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EXPERIMENTAL STUDIES ON THE EFFECTS OF COMMERCIAL KELP HARVESTING IN CENTRAL AND SOUTHERN CALIFORNIA *MACROCYSTIS PYRIFERA* KELP BEDS.¹

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The effects of commercial kelp harvesting were studied in *Macrocystis* kelp beds in southern and central California. Hapteral elongation and branching, as well as plant survivorship, were compared on commercially harvested plants and nearby unharvested control plants. No effects of harvesting were found for any of the variables studied. Frond breakage resulting in winter reduction of surface canopy was much more extreme in central California than in southern California. The results of these studies do not indicate any reason for changing harvesting practices in California.

INTRODUCTION

Giant kelp, *Macrocystis pyrifera* (Linnaeus) C. Agardh, occurs in nearshore waters of the northern hemisphere, from central Baja California to Alaska (Abbott and Hollenberg 1976, North 1971). *M. pyrifera* forests, or kelp beds, are a habitat for a variety of organisms which seek shelter, substrate for attachment, and food. Commercial fisheries for sea urchins, abalone, perch, white seabass, and lobster are conducted within California kelp beds. The abundance and variety of fishes and invertebrates within the kelp bed habitat attract people interested in sportfishing and diving to this nearshore area. The kelp is harvested commercially as a source of raw material for the extraction of algin. The studies reported here were initiated because of concern by the Department of Fish and Game (Miller and Geibel 1973; McCleneghan and Houk, pers. commun.) that commercial kelp harvesting might adversely affect the survivorship of *M. pyrifera* in central California.

Specifically, the following aspects of kelp bed ecology related to holdfast dislodgement were investigated:

- (i) Hapteral elongation and branching rates, which together determine holdfast growth and presumably plant attachment success, were determined at Point Loma and Carmel Bay, California. Plants in commercially harvested and adjacent unharvested control areas were studied.
- (ii) Dislodgement of tagged plants was studied within commercially harvested and nonharvested control areas at Carmel Bay.

¹ Accepted for publication March 1984.

- (iii) The areal extent and abundance of kelp forming the surface canopy, as judged by aerial photographs, was studied for major changes that could signify kelp harvesting effects in beds commercially harvested at Carmel Bay between 1971 and 1977.

MATERIALS AND METHODS

Sites and Harvesting Methods

Central California studies were conducted within Carmel Bay, California (Figure 1), during the period from October 1971 to September 1977. The harvested study site was within a depth range of 15–19m. Control plants in Carmel Bay during 1973 were located approximately 820m north of the harvested site in 14–15m of water. The control area was relocated in 1974 to an area 40m offshore of the harvested study site, because considerable differences in preharvest growth rates were noted between 1973 control and harvested plants. Control plants in the 1974 and 1975 studies grew at depths of 14–18m. Five or six plants were studied at each harvest or control site.

Carmel Bay plants were harvested once during each summer in 1973, 1974, and 1975. During commercial harvesting, fronds are cut by reciprocating blades lowered to a depth of approximately 1m. Fronds are deposited aboard the harvester by a conveyor system, called drapers, while the vessel moves through the kelp bed at approximately 1.5 knots. Scuba diving observations were used to determine the percentage of fronds on experimental plants cut during harvesting.

Over 90% of the experimental plants were cut during standard harvesting procedures in 1974 and 1975. In 1973, however, 45–50% of near-surface fronds on two out of five plants were not cut by routine harvesting. Such escapes of surface fronds are common.

Southern California study sites (Figure 2), located in the central portion of *M. pyrifera* beds adjacent to Point Loma, California, were studied over the period 1971 to 1974. Harvest and control sites were adjacent to each other at depths of 14–15m. As a result of extensive experience in the Point Loma study sites and the studies of Brostoff (1977) relating holdfast growth and development to plant age, the age of the plants used in the southern California studies was known.

Hapteral Elongation and Branching

Hapteral elongation (haptera are the cylindrical, branching structures making up the holdfast, which attach the kelp plants to the substrate) was measured by noting change in length over a 7-day period. Haptera were tagged loosely with colored rubberbands and measured to the nearest mm. Approximately ten haptera were measured per plant. An attempt was made to include all size classes in the measurements for each plant, to minimize biasing the results. In addition, haptera were selected from three sides of the holdfast.

The total length of a hapteron was determined by measuring dichotomies to one side (Figure 3). To reduce error, all measurements were made by the same person (RHM). Different haptera were tagged during pre- and postharvest measurements, because "young" haptera frequently grew over "old" haptera, making the measurement of previously measured haptera impossible or too difficult.

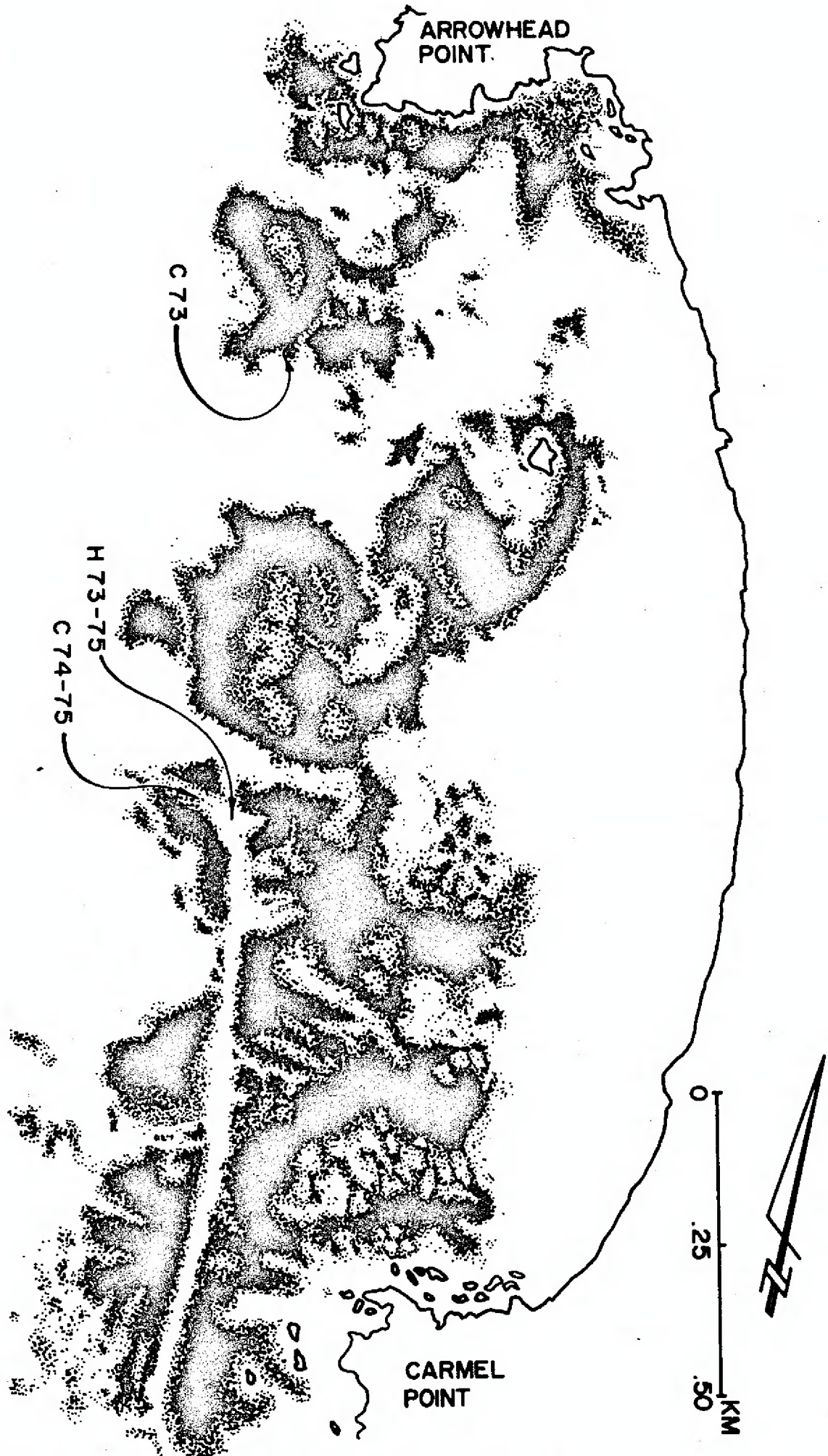


FIGURE 1 Carmel Bay kelp canopy based on aerial photographs taken 4 October, 1971 by the Army Corps of Engineers. The area used to study harvest effects in 1973–1975 is noted as H 73–75. Control plots used in 1973 and 1974–1975 are labeled C 73 and C 74–75, respectively.

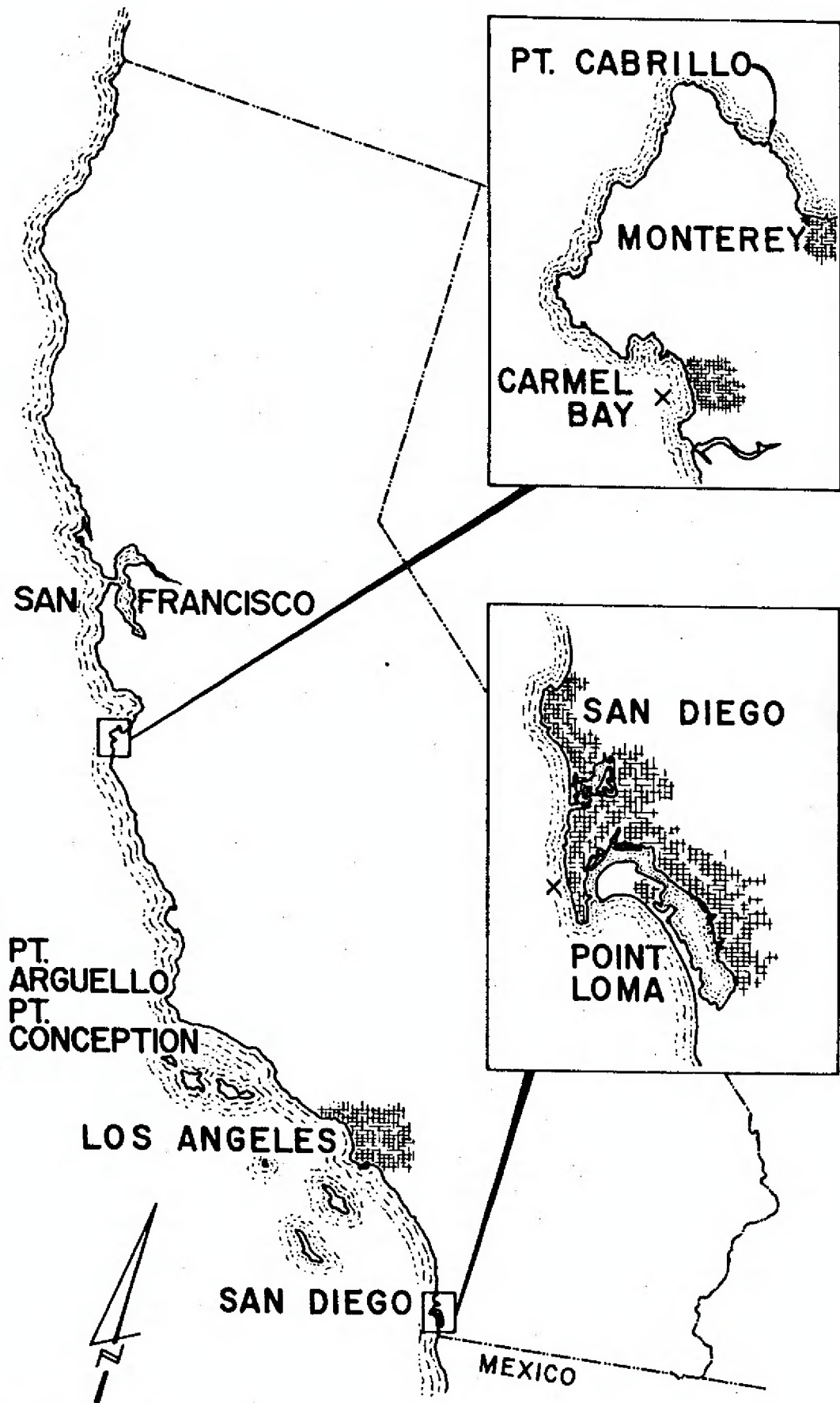


FIGURE 2 Study sites.

Measurements of hapteral branching and elongation were carried out three times during 1974 at the Point Loma study sites. Methods used were the same as those described for Carmel Bay. Elongation measurements were made on plants that were approximately one year old. Branching measurements were made on one-year-old plants as well as three- and five-year-old plants. The plants in the harvested area were first harvested 26 March 1974 and were cut three times during 1974.

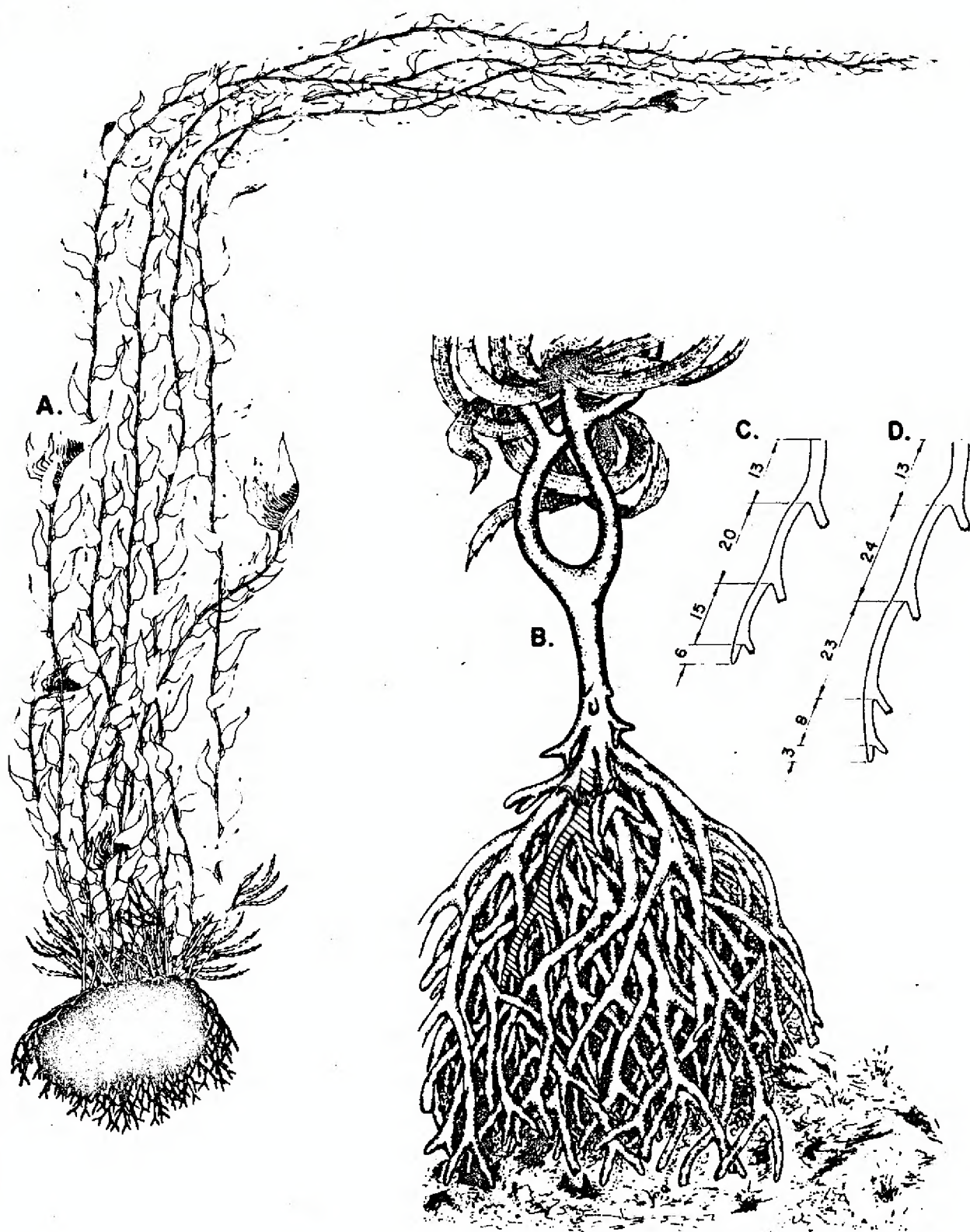


FIGURE 3A. Growth habit of an adult *Macrocystis* with mature fronds forming a surface canopy; B. The primary stipe and numerous haptera comprising the holdfast of an adult *Macrocystis* plant. The blades are sporophylls which are attached to the mature fronds which in turn extend to the surface. The hapteron used to show our measuring techniques is hatched; C. Representation of a hapteron (hatched in B) consisting of four dichotomies with a total length of 54 mm. Only dichotomies to the left were measured; D. The same hapteron showing 17 mm. of growth during 7 days. Intercalary elongation of the hapteron between the dichotomies can be determined by comparing Figures 3-C and 3-D. An additional dichotomy developed during the weeks growth.

Plant Survivorship

During the course of our hapteral elongation and branching studies at Carmel Bay (1972–1977), a total of 36 harvested and 40 unharvested control plants were tagged and their survivorship followed. As a special test for winter survival, 22

control and 21 harvested plants were tagged on 11 October 1974. Plants in the harvest area had been harvested by Kelco once each year from 1971 through 1974, with the harvest in 1974 occurring on 24 June 1974.

Canopy Surface Area

Color infrared aerial photographs taken by the Army Corps of Engineers and the California Department of Fish and Game were used to determine changes in Carmel Bay canopy cover from 1971 through 1977. Aerial photographs for Carmel Bay provide an accurate measure of canopy surface area, because currents in the Carmel Bay kelp bed are negligible (unpublished observations by the authors).

Statistical Treatment

Statistical analyses of hapteral elongation were performed on average daily elongation rates calculated for the following haptera size classes (mm):

1–5, 6–10, 11–20, 21–40, 41–60, 61–80, 81–100. The daily means of each size class ($n = 2$ to 16) were used in the analyses rather than the individual measurements.

Data for average daily hapteral elongation were transformed using logarithmic transformations of dependent and independent variables, because the power curve fit consistently gave the highest coefficient of determinations. Hapteral elongation data were analyzed using ANCOVA as outlined by Dixon and Massey (1957) for (i) differences between means taking regression effects into account, and (ii) equality of slopes for the regression of each group. The differences between individual means, adjusted for length of haptera, were compared with t-test procedure (Snedecor 1967, p. 402). Statistical differences between harvested and control plots for hapteral branching were tested using standard contingency table chi square (X^2) tests.

Results from all statistical tests employed in this study were considered statistically significant if the probability of getting similar results by chance was less than 5%. Results were considered highly significant if the probability of chance occurrence was less than 1%.

RESULTS

Hapteral Elongation

The 1973 Carmel Bay data indicate that hapteral elongation was consistently greater at the unharvested control plot than at the harvested site, both before and after harvesting (Figure 4). In August, haptera at both sites elongated at a slower rate than during the May preharvest measurements. Elongation rates of both harvested and control plants declined by about the same amount. Based on ANCOVA, differences between mean elongation rates for different periods were highly significant, while the differences between slopes were not significant. Student t-tests on differences in mean elongation rates indicate that differences between periods (i.e., May and August) for each plot were highly significant.

Hapteral elongation rates at Carmel Bay control and harvest plots in 1974 were similar, and seasonal variation was less than in 1973 (Figure 5). ANCOVA indicated the differences in mean hapteral elongation rates were highly significant, for different periods, while differences between slopes were not.

Differences in length of haptera between harvested and unharvested plots were not significant based on a t-test. Differences for harvested and unharvested plots for preharvest (May) and postharvest (June) comparisons were significant, indicating seasonal differences in elongation rates.

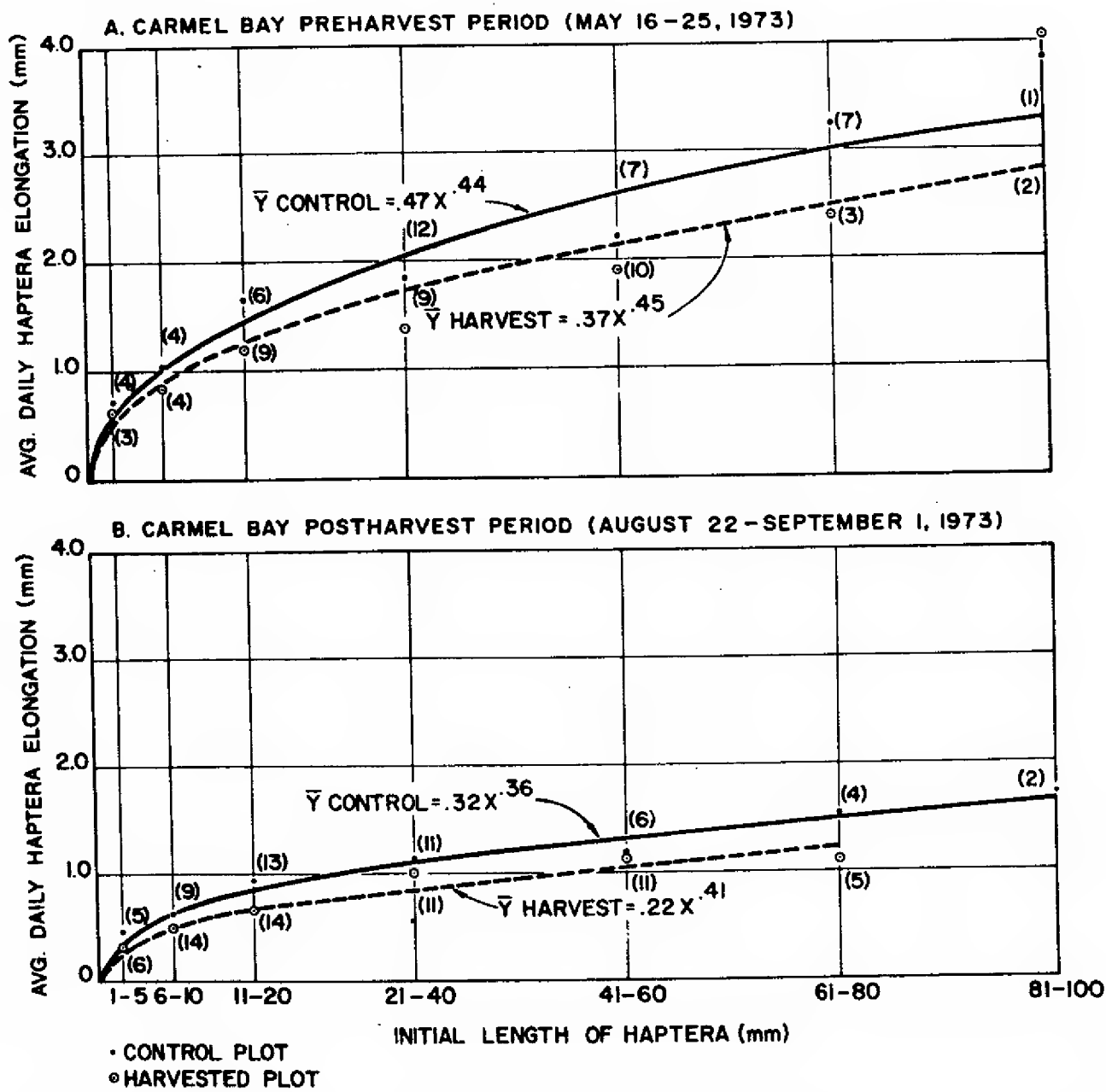


FIGURE 4 Hapteral elongation data from the 1973 preharvest (A) and postharvest (B) studies at Carmel Bay and power curve fits to that data. The number of haptera measured are indicated in parentheses adjacent to the fitted curve for the treatment for which they were taken.

Hapteral Branching

Results of hapteral branching studies did not indicate any consistent trends for Carmel Bay that could be associated with harvesting (Table 1). Statistically significant differences in branching between harvested and control areas occurred in both pre- and postharvest periods. Harvested plants branched more than control plants during two postharvest periods, while control plants exhibited a higher amount of branching during one postharvest period. In 1974, the harvested plot had more branching during the preharvest studies than did the control plants.

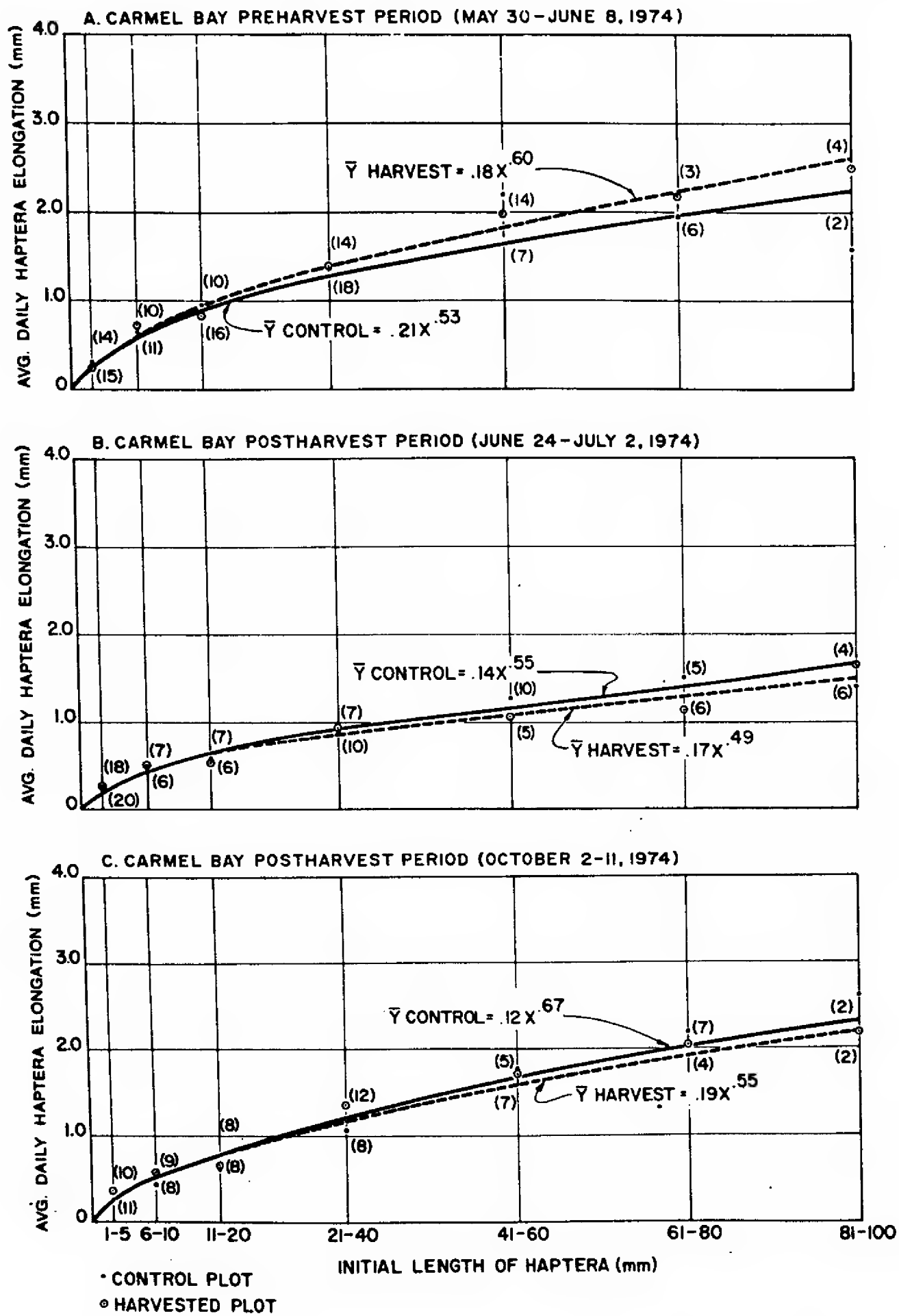


FIGURE 5 Hapteral elongation data from the 1974 preharvest (A), postharvest-1 (B), and postharvest-2 (C) studies at Carmel Bay and power curve fits to that data. The number of haptera measured are indicated in parentheses adjacent to the fitted curve for the treatment for which they were taken.

TABLE 1. Summary of Haptera Branching Results at Carmel Bay.

Study period	Number of plants	Treatment	Branches per week			χ^2 for differences between harvested and control plants	P [χ^2]
			0	1	2		
Preharvest 16-25 v 73	5	Harvested	24	15	1	.41	.81
	5	Control	23	20	1		
Postharvest 24 VIII-1 IX 73	5	Harvested	50	11	0	11.30	.004
	5	Control	27	23	1		
Preharvest 31 V-6 VI 74	6	Harvested	54	26	0	.02	.87
	6	Control	57	26	0		
Postharvest-1 25 VI-2 VII 74	6	Harvested	52	26	0	1.18	.56
	6	Control	51	18	1		
Postharvest-2 2-10 X 74	6	Harvested	39	18	0	3.93	.048
	6	Control	48	9	0		
Preharvest 3-10 VI 75	6	Harvested	30	32	1	14.18	.0008
	6	Control	48	12	0		
Postharvest-1 13-20 VI 75	6	Harvested	39	10	0	.03	.85
	6	Control	43	12	0		
Postharvest-2 7-16 VIII 75	6	Harvested	34	23	2	7.54	.02
	6	Control	47	12	0		

The 1975 Carmel Bay hapteral elongation data indicated variation in elongation rates between harvested and control plots and with time (Figure 6). Haptera in the harvest plot elongated at a more rapid rate than did those in the control plot during the preharvest and July postharvest period. Statistical significance was not tested for in the 1975 data because variances were judged to be heterogeneous based on the F test (Sokal and Rohlf 1969).

The Point Loma data for plants of a uniform age class (i.e., one year) indicated less variation in hapteral elongation with time or between harvested and unharvested control areas at Point Loma than at Carmel Bay (Figure 7). Unlike the Carmel Bay results, differences between slopes were significant for the Point Loma plants between sampling periods.

Point Loma hapteral branching for one-, three-, and five-year-old plants did not differ significantly between harvested and control plants in 1974 during preharvest and two postharvest periods (Table 2). This finding contrasts with Carmel Bay, where significant variability was noted in several instances between periods.

Plant Survivorship

Similar numbers of harvested and control plants, tagged during the course of the hapteral elongation and branching studies at Carmel Bay (1972–1977), were lost. A total of 12 plants was lost from the 36 tagged harvested plants, while 12 plants were lost from the 40 tagged control plants. These data indicate a slightly greater percentage loss of harvested relative to control plants.

Survivorship of harvested and control plants was similar following the special test for winter survival in Carmel Bay, 11 October 1974 through 15 May 1975. The 15 May 1975 count revealed that four of 22 control plants and three of 21 harvested plants were lost during the winter.

Canopy Surface Area

Photographs of the 1971 and 1977 Carmel Bay surface canopy were studied to determine if routine commercial harvesting of Carmel Bay kelp had caused a long-term decrease in the surface canopy area. Surface canopy area was approximately 60 ha in 1971 and 1977 (Figures 1 and 8). The abundance of kelp forming a surface canopy appeared to be similar in harvested and unharvested parts of the bed. The outer margins of the bed in harvested and unharvested areas did not change. Diving observations revealed that these margins were determined by the availability of adequate substrate for holdfast attachment.

A striking seasonal variation in canopy cover occurred every year from 1971 through the winter of 1977. During the late fall and early winter months canopy cover was reduced as much as 95%. Figure 9 is a typical representation of canopy cover in Carmel Bay during the winter. Diving observations indicated that the reduction of surface canopy area was primarily due to a reduction in the number of fronds extending to the surface and not necessarily plant loss.

Ancillary Observations

Two obvious differences between the holdfast structure of central and southern California *Macrocystis pyrifera* were noticed during the course of these studies. In general, the haptera of southern California plants were about twice the diameter of haptera on central California plants. Also, sea urchins in the holdfast interstices were much fewer in the central California kelp beds.

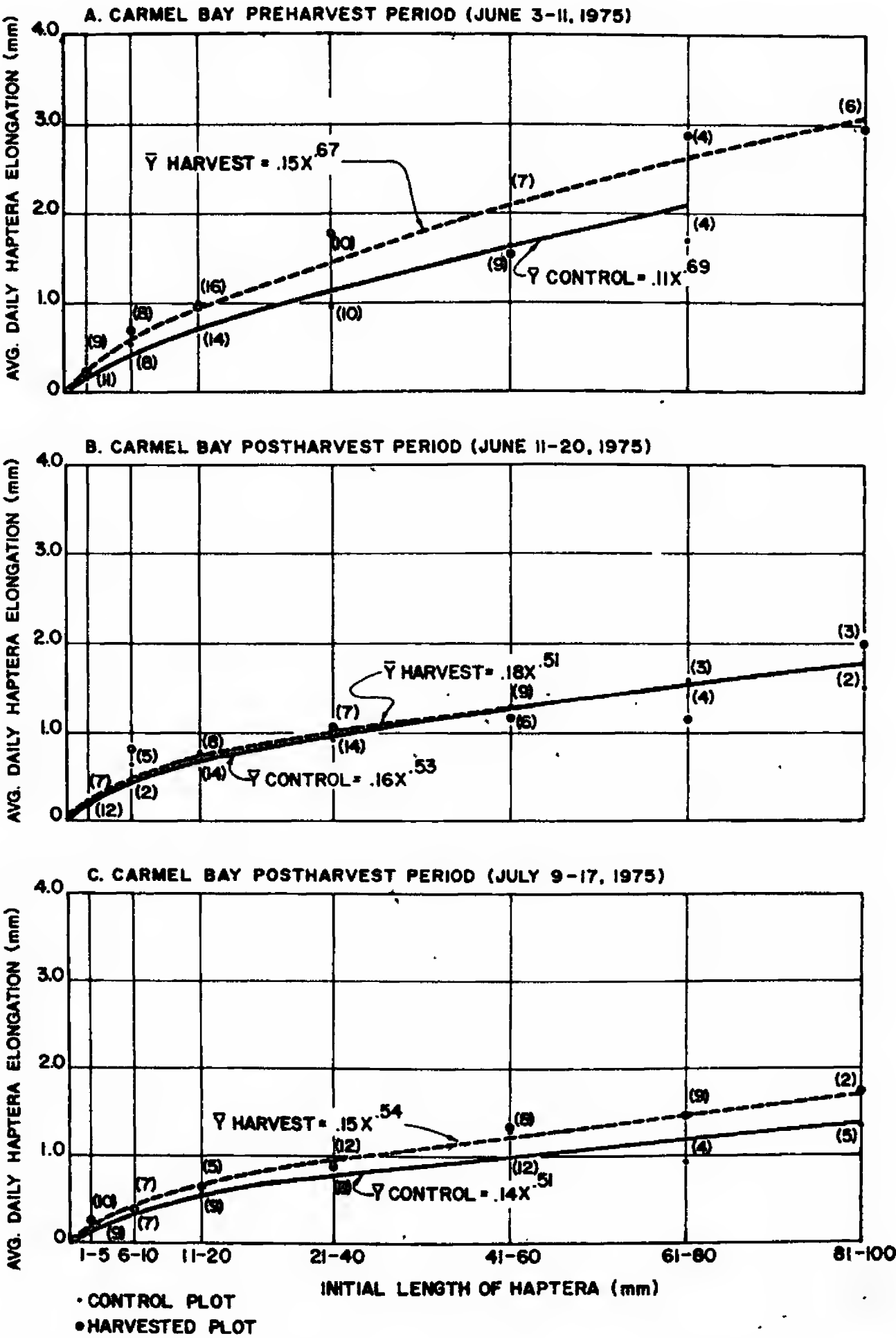


FIGURE 6 Hapteral elongation data from preharvest (A), postharvest-1 (B), and postharvest-2 (C) periods at Carmel Bay in 1975 and power curve fits to that data. The number of haptera measured are indicated in parentheses adjacent to the fitted curve for the treatment for which they were taken.

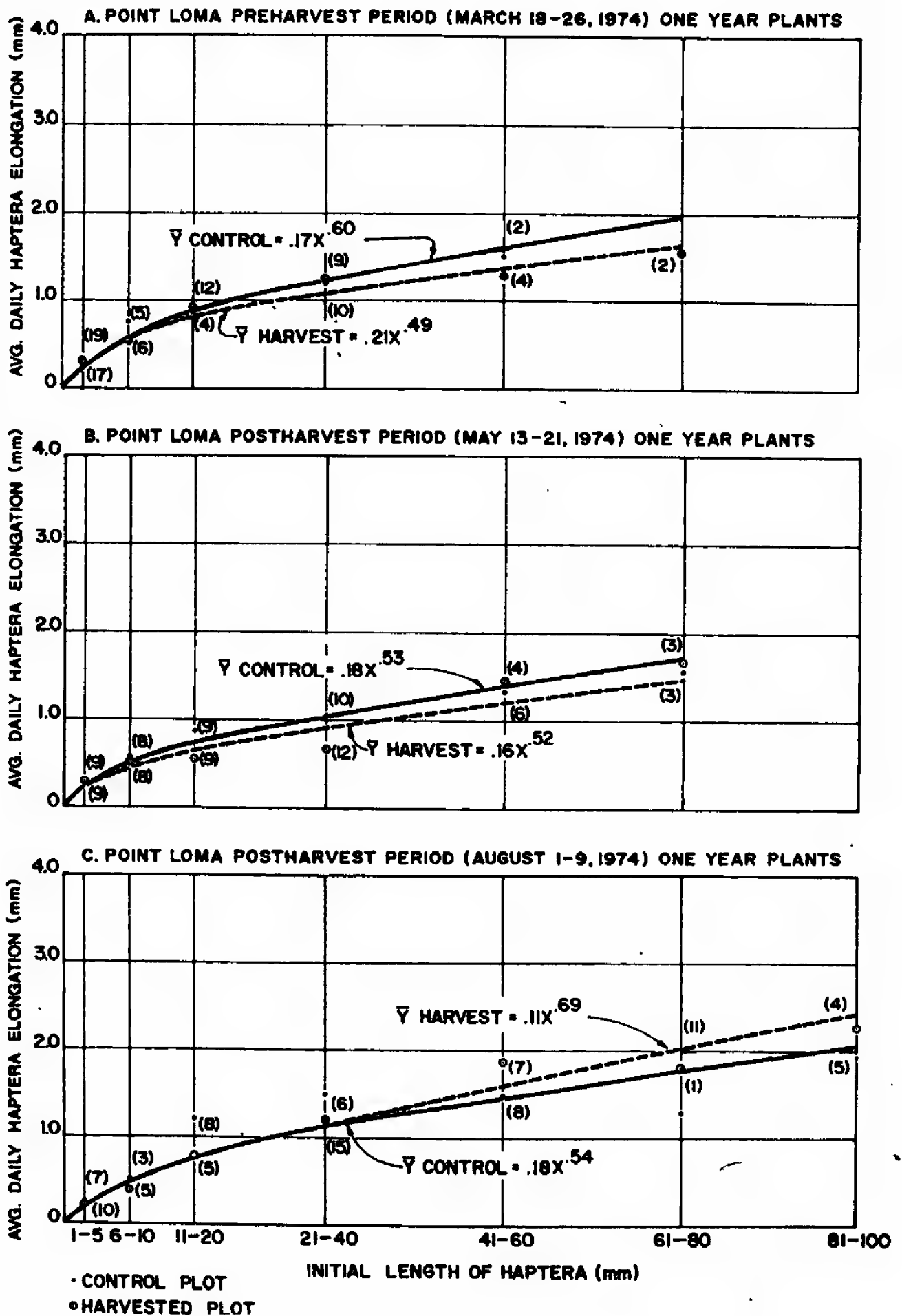


FIGURE 7 Hapteral elongation data from preharvest (A), postharvest-1 (B), and postharvest-2 (C) periods at Point Loma in 1974 and power curve fits to that data. The number of haptera measured are indicated in parentheses adjacent to the fitted curve for the treatment for which they were taken.

TABLE 2 Summary of 1974 Haptera Branching Results for Point Loma.

Study period	Plant age	Number of plants	Treatment	Branches per week			χ^2 for differences between harvested and control plants	P [χ^2]
				0	1	2		
Preharvest 18-25 III 74	1	5	Harvested	30	12	0	.04	.85
		5	Control	32	14	0		
Preharvest 18-25 III 74	5	5	Harvested	33	12	0	.01	.93
		5	Control	26	9	0		
Postharvest—1 13-22 V 74	1	5	Harvested	36	9	1	1.99	.37
		5	Control	28	14	1		
Preharvest 12-22 V 74	3	2	Harvested	12	6	0	1.90	.39
		2	Control	18	1	0		
Postharvest—1 13-22 V 74	5	5	Harvested	38	9	0	3.30	.07
		5	Control	43	3	0		
Postharvest—2 2-9 VIII 74	1	5	Harvested	30	15	1	.46	.80
		5	Control	30	20	1		
Postharvest—2 2-9 VIII 74	3	2	Harvested	15	4	0	.24	.62
		2	Control	17	3	0		



FIGURE 8 Carmel Bay kelp canopy based upon an aerial mosaic taken by the California Department of Fish and Game, 14 September, 1977.



FIGURE 9 Carmel Bay kelp canopy based upon an aerial mosaic taken by the California Department of Fish and Game, 9 January, 1975.

DISCUSSION

Concerns for the effects of kelp harvesting prompted the studies reported here. Our studies have focused on the possibility that kelp harvesting increases the rate of plant dislodgement, by affecting growth processes of the haptera making up the holdfast that attaches the plant to the substrate. Because of the obvious importance of not adversely affecting *Macrocystis* survivorship, the results discussed here are of major significance to those concerned with managing kelp bed resources.

Our studies in southern and central California have covered several aspects of possible harvest effects that could affect plant survivorship. We could not find a significant effect of harvesting on the elongation or branching rates of the haptera forming holdfast structures. Survivorship studies did not indicate a difference in plant loss between harvested and control populations in Carmel Bay. Survivorship studies conducted since 1978 in Carmel Bay support the preliminary studies reported here (Barilotti, unpublished data).

Analysis of aerial photographs from 1971 through 1977 did not reveal any long-term changes in canopy area that could be attributed to kelp harvesting. Studies by Kimura (1980) of the Carmel Bay kelp bed from 1973 through 1979 found that annual kelp harvesting had not altered the seasonal variations in canopy cover of the Carmel Bay bed. With the information now available from our studies, we do not feel commercial kelp harvesting, as currently practiced, has an effect on plant survivorship.

Studies in central California (Miller and Geibel 1973; McCleneghan and Houk, pers. commun.) have reported deleterious effects on kelp survivorship, or processes that might affect survivorship, that must be put in perspective with our findings. The studies by Miller and Geibel are not comparable to ours because they conducted experimental harvests that were not similar to actual commercial harvests. They cut plants at a depth of 10 feet, considerably deeper than the four foot depth allowable by state law, and they harvested five times in a 14 month period. Since Kelco began harvesting the central California resource, one harvest a year has been the practice and there has been only one year (1975) in which two harvests would have been possible. Therefore the frequency of cutting in the Miller and Geibel study was not similar to commercial practice. As noted in other studies (Miller and Geibel 1973; Cowen, C. R. Agegian, and M. S. Foster 1982) the decrease in canopy cover during winter months in central California is the main reason commercial harvests cannot be conducted with a frequency approaching that used by Miller and Geibel.

The significant variability of hapteral branching found in our studies in Carmel Bay that could not be related to harvesting or seasonal factors indicates that hapteral branching is not a reliable measure of possible processes that could affect plant survivorship. Depending on which year's results one chooses to use, it could be concluded that harvesting had no effect, or it increased branching of the haptera, or it decreased hapteral branching. Because of this variability due to unknown factors, the results of McCleneghan and Houk (pers. commun.), showing a significant effect of harvesting on hapteral branching in a one-year study, are difficult to interpret relative to commercial harvesting effects on survivorship.

Because of the difficulty of relating changes in processes that might affect survivorship to actual survivorship changes resulting from harvesting, we recommend that future studies of harvesting effects concentrate on obtaining direct measurements of survivorship. The controlled field experiment approach should be used, where replicate areas are harvested and others are left as controls to measure change against, in order to answer questions directly. Overharvesting would be indicated if a statistically significant decrease in survivorship was noted between harvest and control areas. Such studies are currently in progress in Carmel Bay.

In conclusion, we cannot find any compelling reasons from the studies reported here, or those being conducted in Carmel Bay (Barilotti, unpublished data) to modify current kelp harvesting practices in southern or central California.

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LITERATURE CITED

- Abbott, I. A., and G. J. Hollenberg. 1976. Marine Algae of California. Stanford University Press, Stanford, California. 827 p.
- Brostoff, W. N. 1977. A taxonomic revision of the giant kelp *Macrocystis* in southern California based on morphometric and transplant studies. Thesis, San Diego State University. 75 p.
- Cowen, R. K., C. R. Agegian, and M. S. Foster. 1982. The maintenance of community structure in a central California giant kelp forest. *J. Exp. Mar. Biol. Ecol.* 64:89-201.
- Dixon, W. J., and F. J. Massey. 1957. Introduction to statistical analysis. McGraw-Hill Book Co., New York. 448 p.
- Kimura, R. S. 1980. The effects of harvesting *Macrocystis pyrifera* on understory algae in Carmel Bay, California. Thesis, California State University, Fresno. 108 p.
- Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Dept. Fish and Game, Fish. Bull., (158). 137 p.
- North, W. J. 1971. Introduction and background. Pages 1-97 in Wheeler J. North, ed. The biology of giant kelp beds (*Macrocystis*) in California. *Nova Hedwigia*, 32: Suppl.
- Sokal, R. R., and R. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco. 776 p.
- Snedecor, G. W. 1967. Statistical methods. 5th ed. Iowa State Univ. Press, Ames, Iowa. 534 p.

THE EFFECTS OF CANOPY REMOVAL ON HOLDFAST GROWTH IN *MACROCYSTIS PYRIFERA* (PHAEOPHYTA; LAMINARIALES)¹

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An experiment was conducted to determine whether or not canopy removal affects holdfast growth in *Macrocystis pyrifera*. The rate of haptera divisions that occurred in holdfasts of experimentally harvested plants was compared to the rate on unharvested plants, both grown on artificial substrata. The mean number of divisions in both populations was not significantly different prior to canopy harvest. After the canopy was removed from test plants, an immediate and highly significant decrease in haptera divisions occurred. This effect was still apparent six weeks following the harvest when the experiment was terminated. No corresponding decrease occurred in the control plants. We conclude that kelp canopy removal reduces hapteral divisions and thus slows holdfast growth.

INTRODUCTION

Giant kelp, *Macrocystis pyrifera*, provides important habitat for many marine organisms, especially fish, and is a valuable crop resource for a major California industry. Kelp harvesting, the removal of canopy-forming surface fronds, temporarily destroys canopy habitat in the harvested portion of a kelp forest. If harvesting also had a detrimental effect on plant survivorship, increased plant mortality could adversely affect the entire kelp forest environment. Canopy harvesting may affect holdfast growth by reducing the amount of translocated photosynthate. About 95% of the organic production of *M. pyrifera*, occurs in the upper one meter of water (Towle and Pearse 1973), that region occupied by the kelp canopy. Generally, previous investigations have not examined holdfast growth of harvested plants. Nicholson (1970) reported diminished holdfast growth of *Nereocystis* due to blade removal and reduced productivity of the blades. We examined the effect of canopy removal on haptera division rate in the giant kelp holdfast.

MATERIALS AND METHODS

Thirty-four artificial substrata (steel automobile wheels filled with concrete) were located on a flat sand bottom at a depth of 8 m southeast of Hopkins Marine Station. This area was near an existing kelp bed but sufficiently removed from it that shading by adjacent, non-experimental plants would not occur. The substrata were distributed so that the density of plants was approximately two plants per 10 m². Transplants were gathered from the adjacent natural kelp bed in late April 1974, and ranged from 1 to 2 m in length, each with two stipes. The holdfast was held firmly against the concrete by inserting it in the center of two

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³ Mr. Houk's current address is: Marine Culture Laboratory, Granite Canyon, Coast Route, Monterey, California 93940.

rubber bands stretched across the diameter of the substratum. The young kelp plants became firmly attached to the concrete surface in an average of 12 days.

An arbitrary line divided the transplants into two groups; control plants were on one side with test plants opposite them. This arrangement minimized shading of the test population by the control bed. Of the 17 plants in both the control and test populations, only nine randomly selected plants in each group were used for the haptera growth study. The remaining plants in each group were to provide replacements for those kelp plants in the haptera growth study that failed to thrive, were damaged or lost. Frond counts, performed on all plants, were made 1 m above the sea bed and $\frac{1}{2}$ m below the water surface. Various colored rubber bands were loosely tied around different haptera on one randomly selected side of the holdfast. Holdfast photographs of each of nine test and nine control plants were taken one week apart. Using the tagged haptera as reference points when comparing slide pairs, conspicuous haptera in the holdfast mass could be identified. The distal ends of 30 haptera on each of nine control and nine test plants were examined and the number of divisions (zero, one, two, or three) recorded for several one week intervals preceding and subsequent to canopy removal of the test group.

The canopy of plants in the test group was cut by divers on 16 October 1974. The kelp canopy was cut at 1.2 m beneath the surface in order to be consistent with the provisions set forth by the Fish and Game Commission for commercial kelp harvesting operations. Harvested stipes were counted and weighed for each plant. Also, several plants were weighed at harvest in order to estimate the percent biomass removed from cut plants.

The Kolmogorov-Smirnov test for goodness of fit was performed in order to examine whether the number of haptera divisions in each of the two plant groups were normally distributed at each of the six sampling periods. An F-test was then carried out for each sampling period to affirm the assumption of equal variances in the two populations. With this assumption validated for all six samples, a t-test was performed for each period to compare the mean number of haptera divisions per plant between the control and test groups. In addition, we compared the proportion of division types (zero, one, two, and three divisions) in the control and test populations using a two-way classification χ^2 -distribution test of homogeneity for each sampling period.

RESULTS

The number of bottom fronds produced by both groups of plants was very similar throughout the period of study, even after canopy removal of the test group (Figure 1). The number of surface fronds in both groups was similar up to the time of canopy removal (Figure 2). The 16 October canopy harvest of all 17 plants in the test group yielded a total of 126 fronds with a wet weight of 339 kg; this amount removed about 50% of the biomass which is within the range reported for commercial harvesting operations (Sargent and Lantrip 1952; Clendenning 1968; North 1968a, 1968b; R. McPeak, Kelco Co., pers. commun.).

The mean number of haptera divisions per plant dramatically decreased in the test group after the harvest (Figure 3). A slight decrease in the mean number of hapteral divisions also occurred in the control group. Bottom frond numbers

for both groups remained unchanged (Figure 1), but some of the canopy-forming fronds of the control group were lost due to a small storm in the week following the harvest (Figure 2).

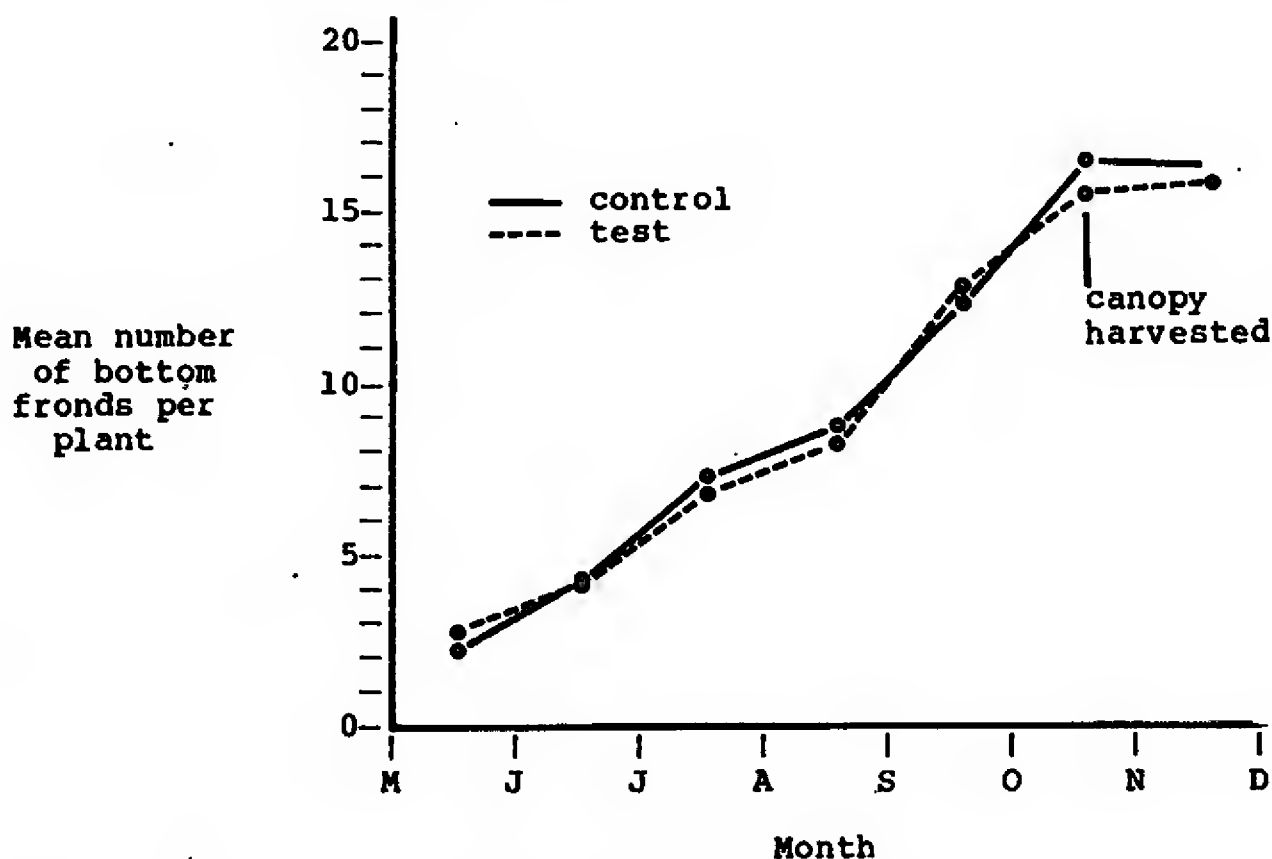


FIGURE 1. Mean number of bottom fronds per plant in both the control and test groups from May to December 1974.

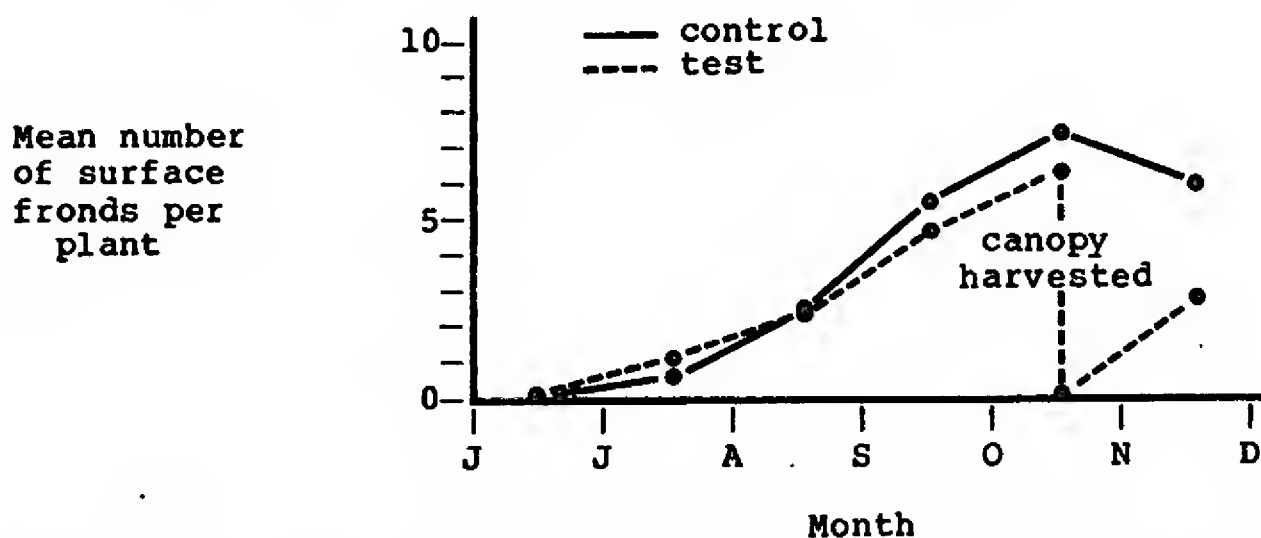


FIGURE 2. Mean number of surface fronds per plant in both the control and test groups from June to December 1974.

The Kolmogorov-Smirnov test showed that the number of haptera divisions in both groups at each of the six sampling periods was not significantly ($P > 0.05$) different from normal distributions. F-values calculated for the six sampling dates lay within the region of acceptance for the 5% significance level (Table 1). Therefore, the hypothesis of equal variance between the cut and control groups for each period was accepted.

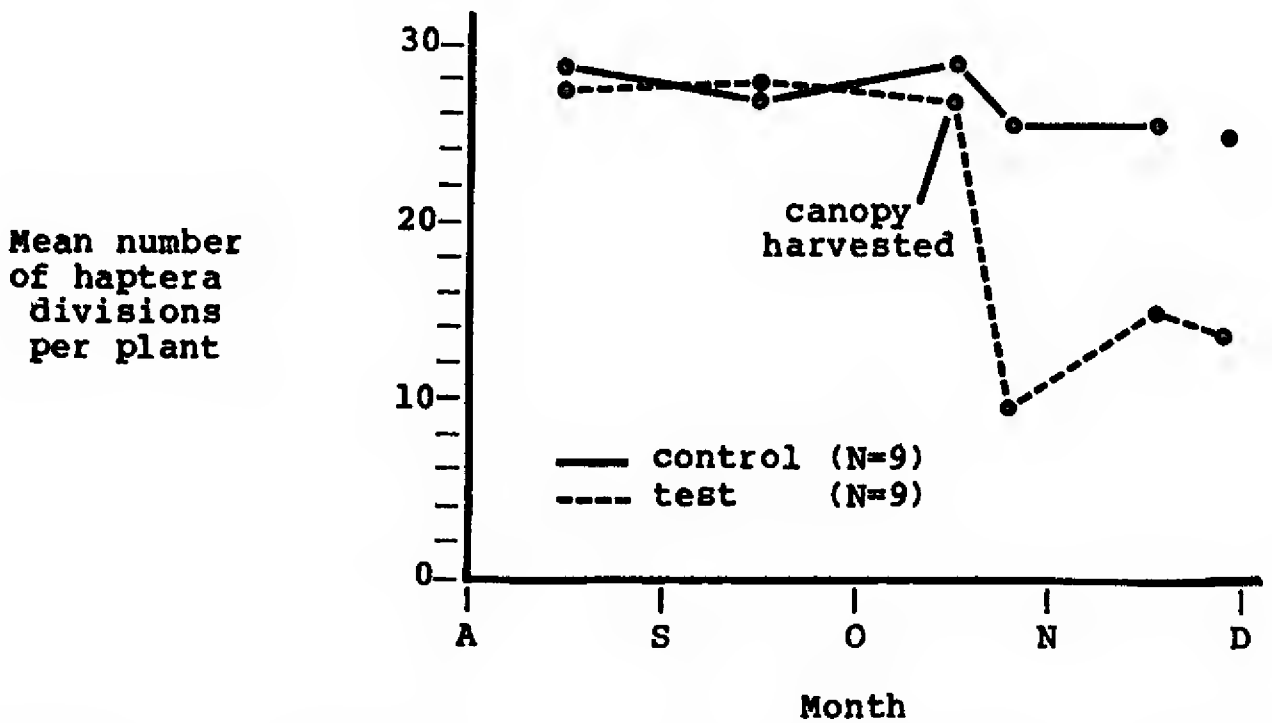


FIGURE 3. Mean number of haptera divisions per plant that occurred in both the control and test groups from August to December 1974.

TABLE 1. Calculated F and t Values for the Mean Number of Haptera Divisions in Both Test and Control Populations of *Macrocystis pyrifera* Before and After an Experimental Canopy Harvest: Monterey, CA, 1974.

Date	Mean no. haptera divisions		F values ¹	t values ²
	test	control		
Aug 8-15	27.33	28.22	2.56	-0.54
Sep 10-17	25.78	27.11	0.68	-0.50
Oct 9-16	25.67	28.78	0.76	-1.40
Oct 16	canopy harvested from test plants			
Oct 16-23	10.56	25.33	2.41	-8.61
Nov 13-20	15.89	24.56	1.74	-5.80
Nov 20-27	14.33	25.00	1.45	-5.11

¹ Critical region ($P < 0.05$): $F < 0.226$ or $F > 4.43$

² Critical region ($P < 0.05$): $F < -2.120$ or $t > 2.120$

A series of two-tailed student t-tests showed that the mean number of haptera divisions in both control and test groups was not significantly different prior to harvest (Table 1). Following the harvest, the difference in the mean number of haptera divisions between control and test groups was highly significant. ($P < 0.001$); canopy removal significantly reduced haptera division in harvested plants.

The X^2 analyses (Table 2) showed that, for the three samples preceding the harvest, there was no significant difference in the proportion of haptera divisions per category between control and test groups. However, for the three periods following canopy removal of the test group, the difference in proportion of divisions within each category between control and test groups was highly significant ($P < 0.001$); canopy removal caused an increase in the number of non-dividing haptera with a concomitant decrease in the rate of haptera division.

TABLE 2. Contingency Tables and Calculated X^2 Values for Differences Between the Number of Haptera Divisions in Test and Control Populations of *Macrocystis pyrifera* Before and After an Experimental Canopy Harvest: Monterey, CA, 1974.

Date	Group	Number of divisions				χ^2 values ¹	P (χ^2)
		0	1	2	3		
Aug 8-15	test	51	199	13	7	0.38	.94
	control	56	202	14	8		
Sep 10-17	test	65	185	13	7	2.49	.48
	control	52	200	10	8		
Oct 9-16	test	63	190	10	7	7.58	.06
	control	41	205	18	6		
Oct 16	canopy harvested from test plants						
Oct 16-23	test	178	89	3	0	109.80	.00
	control	58	199	10	3		
Nov 13-20	test	133	131	6	0	37.65	.00
	control	66	189	13	2		
Nov 20-27	test	146	119	5	0	55.30	.00
	control	64	192	9	5		

¹ Critical region: $X^2 > X^2_{.95} (3) = 7.81$

DISCUSSION

Commercial harvesting of *Macrocystis* must be no greater than 1.2 m below the surface of the water at the time of cutting as specified by the Fish and Game Commission, Title 14, Sec. 165 (State of California 1982). There are no restrictions regarding (i) the frequency with which the kelp bed may be cut, (ii) the percentage of canopy that can be removed from a contiguous kelp bed, or (iii) the amount of kelp that can be removed from a bed annually (Miller and Geibel 1973).

Ghelardi (1971) found that living haptera comprised only a thin outer layer of the *Macrocystis* holdfast; the central portion was decayed and composed of accumulated mineral, plant, and animal debris. Leighton (1971) reported that *Macrocystis* holdfasts often harbor large numbers of sea urchins whose grazing on hapteral tissue causes "cavitation" of the holdfast thereby weakening it and resulting in dislodgment of entire plants along with a large portion of the holdfast.

Rosenthal, Clarke, and Dayton (1974) believed (i) storm, (ii) plant entanglement, and (iii) kelp harvesting acting synergistically, were responsible for most plant losses. In separate studies, both they and Gerard (1976) reported that plant mortalities were due to detachment of the entire plant at the holdfast-substratum interface. These studies suggest that holdfast attachment is a vulnerable point and that reduced holdfast growth could contribute to premature plant mortality.

Miller and Geibel (1973) conducted studies on the effects of canopy harvesting *M. pyrifera* off Monterey. They reported that three cuttings of the same plants during a calendar year resulted in loss of all plants, including holdfasts, during the following winter. A pilot study conducted by them on 10 giant kelp plants demonstrated that fewer haptera grew across a cord tied around the holdfast of canopy harvested plants than did on the control plants. It was theorized that canopy removal decreased holdfast efficiency by inhibiting haptera growth and thereby increased plant mortality.

Haptera lack an apical meristem (Smith 1939), thus growth is probably through intercalary elongation. We observed that (i) dichotomous branching occurred near the distal end of each hapteron, (ii) generally, internode length was similar, even on different plants, and (iii) a hapteron would usually dichotomize (divide) only after some elongation had been achieved. Holdfast growth then, we assumed, would be reflected in the rate of haptera division.

Canopy removal of test plants not only adversely affected the mean number of haptera divisions but also changed the proportion of divisions. The control group maintained a higher rate of division and had fewer instances of non-dividing haptera than did the test group subsequent to canopy harvest. The difference between the two groups remained significant for 6 weeks following the harvest when the experiment was terminated.

The slight decrease in the mean number of hapteral divisions which occurred in the control group is probably attributable to the loss of some canopy forming fronds due to a storm that occurred during the week following the harvest. We suspect that although most canopy-forming fronds of the control group remained, enough fronds were lost to effectively reduce photosynthate production and translocation to the holdfast. The test plants were not affected by the storm as all canopy-forming fronds had been harvested previously.

Finally, several holdfasts were removed from the substratum and examined. Generally, a holdfast of about 40 cm basal diameter had only the outer perimeter of plant material securely attached to the substratum; the core was black and decaying. The width of this band of attached undecayed haptera varied from about 1 cm to 6 cm. Since this narrow band of healthy, living haptera probably represents the region of firmest attachment, reduced growth of new haptera to replace those becoming senescent could negatively affect plant survivorship.

Results of this study using haptera divisions as an indicator of holdfast growth showed that there was an immediate and dramatic reduction in holdfast growth following kelp canopy removal. Haptera of harvested plants divided much more slowly than those haptera on the unharvested control plants. Plants that have had over 50% of their biomass removed, and the most photosynthetically productive part of their thallus at that, may translocate most of the remaining fraction of excess assimilate into newly developing fronds at the expense of translocation to the holdfast. This strategy would maximize the growth of those unharvested fronds; a surface canopy would be reestablished in the shortest period of time possible but at the expense of holdfast growth. Each type of plant mortality, detachment due to age, storm, entanglement, and harvesting, would be increased by impaired holdfast growth because reduced haptera growth must reduce the effectiveness of holdfast attachment.

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LITERATURE CITED

- Clendenning, K.A. 1968. Harvesting effects on canopy invertebrates and on kelp plants. Pages 219–222 in W.J. North and C.L. Hubbs, eds. Utilization of kelp-bed resources in Southern California. Calif. Dept. Fish and Game, Fish Bull., (139).
- Gerard, V.A. 1976. Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California. Dissertation. Univ. Calif., Santa Cruz. 173 pp.
- Ghelardi, R.J. 1971. "Species" structure of the animal community that lives in *Macrocystis pyrifera* holdfasts. Pages 381–420 in W.J. North, ed. The biology of giant kelp beds (*Macrocystis*) in California. Beih. Nova Hedwigia, 32.
- Leighton, D.L. 1971. Grazing activities of benthic invertebrates in Southern California kelp beds. Pages 421–453 in W.J. North, ed. The biology of giant kelp beds (*Macrocystis*) in California. Beih. Nova Hedwigia, 32.
- Miller, D.J., and J.J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dept. Fish and Game, Fish Bull., (158): 1–137.
- Nicholson, N.L. 1970. Field studies on the giant kelp *Nereocystis*. J. Phycol., 6:177–182.
- North, W.J. 1968a. Effects of canopy cutting on kelp growth: comparison of experimentation with theory. Pages 223–254 in W.J. North and C.L. Hubbs eds. Utilization of kelp-bed resources in Southern California. Calif. Dept. Fish and Game, Fish Bull., (139).
- . 1968b. Concluding discussion, Pages 255–260 in W.J. North and C.L. Hubbs eds. Utilization of kelp-bed resources in Southern California. Calif. Dept. Fish and Game, Fish Bull., (139).
- Rosenthal, R.J., W.D. Clarke, and P.K. Dayton. 1974. Ecology and natural history of a stand of giant kelp, *Macrocystis pyrifera*, off Del Mar, California. Fish. Bull., 72(3):670–684.
- Sargent, M.C., and L.W. Lantrip. 1952. Photosynthesis, growth, and translocation in giant kelp. Amer. J. Bot., 39(2):99–107.
- Smith, A.I. 1939. The comparative histology of the Laminariales. Amer. J. Bot., 26:571–585.
- State of California. Title 14, Natural Resources. Division 1, Fish and Game Commission—Department of Fish and Game. Orders, Rules, and Regulations for 1982.
- Towle, D.W., and J.S. Pearse. 1973. Production of the giant kelp *Macrocystis*, estimated by *in situ* incorporation of ^{14}C in polyethylene bags. Limnol. Oceanogr., 18:155–159.

FISH FOOD HABITS ALONG A POLLUTION GRADIENT¹

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The distribution and food habits of eight species of demersal fishes were examined along a pollution gradient on the mainland shelf near Los Angeles, California. Along the gradient of increasing municipal wastewater effects: i) the diversity and richness of the benthic infauna (potential fish prey) declined, ii) the proportion of polychaetes in grab samples increased while the proportions of crustaceans and molluscs decreased, iii) the abundance, richness, and diversity of demersal fishes decreased, but while some species of fishes declined in abundance other species increased.

Changes in abundance of fishes along the pollution gradient were related to the food habits of the fishes and the distribution and abundance of their prey. The abundance of longspine combfish, *Zaniolepis latipinnis*, yellowchin sculpin, *Icelinus quadriseriatus*, California tonguefish, *Symphurus atricauda*, speckled sanddab, *Citharichthys stigmaeus*, and hornyhead turbot, *Pleuronichthys verticalis*, decreased along the gradient of increasing wastewater effects. The first four species fed primarily on benthic, epibenthic, and nektonic crustaceans, and the hornyhead turbot fed on several species of polychaetes that were rare or absent at stations strongly affected by wastewater discharge. The abundance of English sole, *Parophrys vetulus*, Dover sole, *Microstomus pacificus*, and Pacific sanddab, *Citharichthys sordidus*, increased along the pollution gradient. The proportion of polychaetes increased and the proportion of crustaceans decreased in the diet of these species along the pollution gradient.

INTRODUCTION

The distribution of fishes in polluted areas has been examined by several investigators. Bechtel and Copeland (1970) and Haedrich (1975) showed that the diversity (H') of fishes was lower in polluted areas when compared to unpolluted areas. Bechtel and Copeland (1970) attributed this to stress eliminating the more sensitive species thereby reducing competition and allowing the more resistant species to increase in abundance. Haedrich (1975) showed that the decreased diversity of fishes in polluted estuaries was accompanied by increased faunal similarity between seasons when compared to unpolluted estuaries. He argued, to the extent that annual succession of fishes existed in unpolluted estuaries, a disturbance such as pollution would render the habitat less suitable. Annual succession would therefore decline and faunal similarity between seasons would increase.

Carlisle (1969), Allen (1977), and Mearns (1981) examined the abundance of demersal fishes in otter trawl samples from the mainland shelf in southern California. They found that some species were more abundant (enhanced) and other species were less abundant (depressed) near municipal wastewater outfalls when compared to areas some distance away. In general, the diversity of trawl-caught fishes was lower near major outfalls than in control areas (Mearns 1973, 1979; Allen 1977; Allen and Voglin 1976).

This study examines the distribution and food habits of some common near-shore demersal fishes in an area of wastewater discharge off southern California.

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The data were collected originally for a fish food habits study (Kleppel, Word and Roney 1982). Because of the lack of information about the effects of wastewater discharge on marine fish populations (Boesch 1982), the data were recast to examine the hypothesis that enhancements and depressions of fish abundance around municipal wastewater outfalls are a result of the food habits of the fishes and the altered distributions of their prey.

Study Area

The study took place in the coastal waters of the greater Los Angeles metropolitan area (Figure 1). The mainland shelf around Los Angeles has received anthropogenic domestic and industrial wastes since 1894 (Tillman and Bargman 1973). In 1981, the City of Los Angeles discharged 107.6 metric tons (mt) of suspended solids per day (39,270 mt/yr) through a 60 m deep (8.3 km long) outfall and 126.0 mt of total solids per day (46,000 mt/yr) through a 100 m deep (11.3 km long) outfall in Santa Monica Bay (Figure 1). The County of Los Angeles discharged 230.1 mt of suspended solids per day (84,000 mt/yr) through three outfalls located between 30 and 60 m on the Palos Verdes shelf (Schafer 1982) (Figure 1).

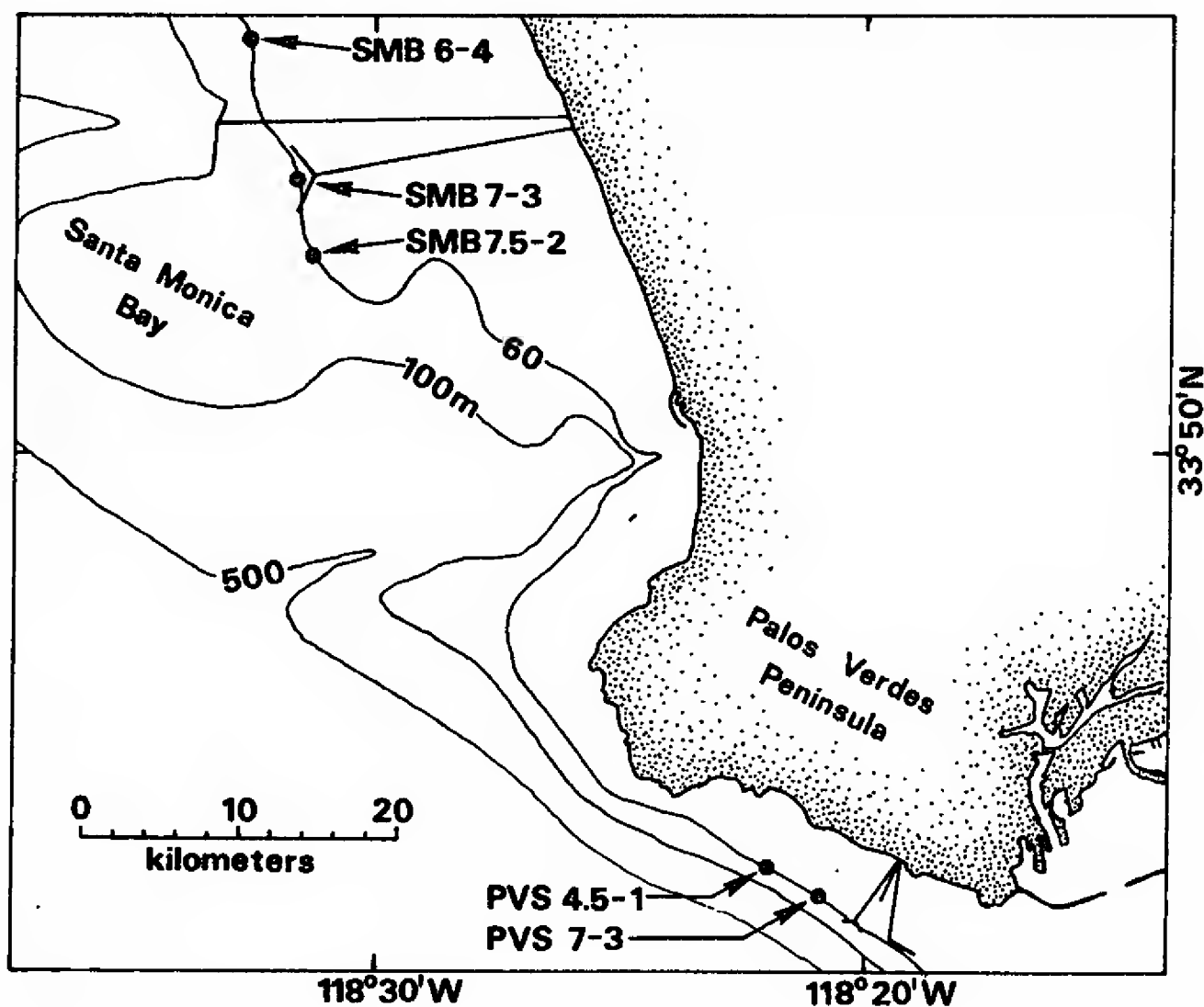


FIGURE 1. Location of sampling stations and outfalls in Santa Monica Bay (SMB) and on the Palos Verdes shelf (PVS). In SMB the outfall discharging at 60 m is the 8.3 km outfall and the outfall discharging at 100 m is the 11.3 km outfall.

MATERIALS AND METHODS

Five stations that ranged from relatively unaffected to strongly affected by wastewater discharge were selected on the 60 m isobath in Santa Monica Bay (SMB) and on the Palos Verdes shelf (PVS) from a larger array of stations sampled regularly by Los Angeles City and County Sanitation Districts. The original station numbers have been retained for continuity. The stations were sampled during the day on 27 and 28 June and again on 7 and 11 December, 1979. Two benthic grabs and one otter trawl were taken at each station.

Grabs were taken with a modified 0.1 m² Van Veen grab. Grab samples for infauna were sieved through a 1 mm screen and the retained contents were fixed in 5% buffered formalin aboard ship. In the lab, the grab samples were washed in freshwater and preserved in 70% ethanol. The animals were sorted and identified with a binocular microscope. Grab samples for sediment analyses were subsampled with a 2 cm deep core and the samples were frozen. Total volatile solids (TVS) was determined by drying the samples to a constant weight at 60°C, burning the samples in a muffle furnace at 500°C for 2 hours, and reweighing; the percent weight loss is TVS. Percent sand was determined by drying the samples to a constant weight at 60°C and washing them through a 63 μ USGS seive; the retained portion was dried to a constant weight, reweighed, and the percent of the sample $> 62 \mu$ was calculated.

Fishes were collected with a 7.6 m headrope otter trawl with a 3.8 cm body mesh and a 1.3 cm cod-end liner towed at 2–3 knots for 10 minutes. Fishes in the trawl samples were counted, measured (to the nearest mm board standard length), and fixed in 10% buffered formalin aboard ship. In the lab, the stomachs were removed and preserved in 70% ethanol; the contents of the stomachs were sorted and identified to the lowest taxon possible.

Diversity was calculated by the Shannon-Weiner information function:

$$H' = - \sum_{i=1}^s p_i \log_{10} p_i$$

where p_i is the proportion of the i th species and s is the number of species in the sample.

Percent similarity between samples was calculated by:

$$PS = 100 \sum_{i=1}^s \min (p_{i1}, p_{i2})$$

where p_{i1} = the proportion of species i in sample one, p_{i2} = the proportion of species i in sample two, and s = the total number of species in both samples.

The study stations were ranked in order of increasing wastewater effects based on several physical and chemical sediment parameters directly attributable to wastewater discharge (Table 1). The order was determined by ranking the stations for each parameter individually from least to most affected and then summing the ranks for each station.

TABLE 1. Physical And Chemical Parameters Measured At The Study Stations in Santa Monica Bay (SMB) And On The Palos Verdes Shelf (PVS). The Stations Are Arranged In Increasing Order of Wastewater Effects (From SMB 7.5-2 to PVS 7-3) Based On Sediment Analyses. The Order Was Determined By Ranking The Stations For Each Parameter (Except Percent Sand) From Least To Most Affected And Then Summing The Ranks For Each Station.

Station	Percent sand ($> 62\mu$)	Total volatile solids (%)	5-day BOD (mg/kg) ¹	Total PCB (ppm) ²	Cd (ppm) ³	Cr (ppm) ³	Zn (ppm) ³
SMB 7.5-2	41.1	3.2	220	.060	2.1	138	92
SMB 6-4	78.9	3.6	630	.066	2.8	73	79
SMB 7-3	39.6	3.8	910	.110	3.8	118	113
PVS 4.5-1	50.7	17.0	15,180	.880	21.0	631	713
PVS 7-3	67.5	19.8	15,500	.952	27.1	802	993

¹ Bascom (1978)

² R. Gossett, SCCWRP, pers. commum.

³ SMB data from: Jan and Hershelman (1980); PVS data from: G.P. Hershelman, SCCWRP, pers. commum.

While the stations do not constitute a geographical gradient (i.e. a linear transect away from an outfall), they do constitute an effects gradient. The justification is as follows: i) The physical properties of the sediments are similar in the two areas as reflected by the proportion of the sediments $> 62\mu$ (Table 1). A more extensive series of percent sand determinations was made for 60 m stations in Santa Monica Bay and on the Palos Verdes shelf by Word and Mearns (1979). The sand content of Santa Monica Bay samples ($\bar{x} = 38.9\%$, $SD = 25.4$, $N = 13$) was not significantly different from the sand content of Palos Verdes samples ($\bar{x} = 51.5\%$, $SD = 20.7$, $N = 9$) (t-test, $.20 < p < .50$); ii) The direction and speed of water currents on the mainland shelf are similar in the two areas (Hendricks 1980); iii) The composition of the infauna at the five stations ranged from assemblages nearly indistinguishable from control areas to assemblages typical of areas of high organic enrichment. (Pearson and Rosenberg 1978).

RESULTS

Grab Samples

The proportion of polychaetes in the grab samples (Table 2) was positively correlated with the gradient of increasing wastewater effects [Spearman $r_s = .839$, $.002 > p > .005$; the June and December samples were combined because there was no systematic difference in the numbers of infaunal animals collected (sign test, $p = .50$)]. The proportion of crustaceans ($r_s = -.858$, $.002 < p < .005$) and molluscs ($r_s = -.542$, $.10 < p < .20$) were negatively correlated with the gradient of increasing wastewater effects.

The polychaete fauna was most diverse at SMB 7.5-2 and SMB 6-4 (Table 3), although few polychaetes were collected at the latter station in December (Table 2). *Capitella capitata* was the most abundant polychaete at the remaining stations (Table 3).

The crustacean fauna was most diverse at SMB 7.5-2 and SMB 6-4 (Table 3). Gammarid amphipods comprised about 50% of the crustaceans collected at SMB 7.5-2, about 5% at SMB 6-4, and less than 1% at the remaining stations. Ostracods (primarily *Euphilomedes* spp.) comprised about 90% of the crustaceans collected at SMB 6-4 and SMB 7-3, and less than 1% at the remaining stations. Crustaceans were virtually absent at PVS stations (Table 2).

TABLE 2. Percent Of Individuals In 0.1 m² Benthic Grab Samples In Major Infaunal Groups In June (J) And December (D); N = Total Number Of Individuals Collected.

Station	<i>Polychaeta</i>		<i>Crustacea</i>		<i>Mollusca</i>		<i>Echinodermata</i>		N	
	J	D	J	D	J	D	J	D	J	D
SMB 7.5-2	44.9	45.7	23.4	20.2	14.8	19.2	10.2	9.5	461	569
SMB 6-4	16.8	0.1	36.9	40.3	45.3	59.0	0.2	0.6	1,328	914
SMB 7-3	51.3	72.7	13.9	10.3	34.5	16.0	0.0	0.2	798	407
PVS 4.5-1	49.0	90.0	5.2	1.0	34.4	8.6	0.0	0.1	96	807
PVS 7-3	94.8	98.1	0.7	0.0	4.5	1.3	0.0	0.0	290	1,029

Otter Trawls

Twenty-six species of fishes representing 2310 individuals were collected in 10 otter trawls (Table 4). Twenty-four species and 1163 individuals were collected in five otter trawls in June and 24 species and 1147 individuals were collected in five otter trawls in December. The number of fishes collected in the trawls was negatively correlated with the gradient of increasing wastewater effects [$r_s = -.736$, $.02 < p < .05$; the June and December samples were combined because there was no systematic difference in the number of individuals collected (sign test, $p = .50$)]. Species richness ($r_s = -.636$, $.05 < p < .10$) and diversity ($r_s = -.421$, $.20 < p < .50$) were also negatively correlated with the gradient of increasing wastewater effects. The percent similarity between June and December samples generally increased along the gradient of increasing wastewater effects and was negatively correlated with total annual diversity (calculated from combined June and December samples; $r_s = -.900$, $p = .10$).

Stomach Analyses

Eight widespread and abundant demersal fish species were selected for stomach analyses. June and December samples were combined because there were no major differences in food habits at the taxonomic level on which we were focusing and because there were no significant size differences among the predators between seasons (Mann-Whitney U-test, $p > .05$). The diets of the longspine combfish, *Zaniolepis latipinnis*, yellowchin sculpin, *Icelinus quadriseriatus*, California tonguefish, *Symphurus atricauda*, and speckled sanddab, *Citharichthys stigmaeus*, were dominated by crustaceans ($\bar{x} = 76\%$, $SD = 7$, $N = 12$) (Table 5). These fishes were common at SMB 7.5-2 and SMB 6-4, uncommon at SMB 7-3, and rare or absent at PVS 4.5-1 and PVS 7-3. The diet of the hornyhead turbot, *Pleuronichthys verticalis*, was dominated by polychaetes ($\bar{x} = 73\%$, $SD = 9$, $N = 3$) (Table 5); hornyhead turbot was collected in SMB but not on the PVS. The remaining species were collected at most stations along the gradient. The diet of the English sole, *Parophrys vetulus*, was comprised of polychaetes, nematodes, and crustaceans (Table 5). The diets of Pacific sanddab, *Citharichthys sordidus*, and Dover sole, *Microstomus pacificus*, were dominated by crustaceans in SMB ($\bar{x} = 70\%$, $SD = 21$, $N = 5$) and polychaetes on the PVS ($\bar{x} = 61\%$, $SD = 8$, $N = 4$) (Table 5).

DISCUSSION

Along the gradient of increasing wastewater effects, the infauna changed from a diverse, species-rich assemblage of crustaceans, polychaetes, and molluscs typical of control areas to a strongly dominated (by *C. capitata*), species-poor assemblage of polychaetes and molluscs typical of organically enriched areas (Pearson and Rosenberg 1978, Boesch 1982) (Table 3).

TABLE 3. Relative Abundance (%) of Dominant Organisms in 0.1 m² Benthic Grab Samples At the Study Stations by Month.

		<i>Polychaeta</i>	<i>Crustacea</i>	<i>Mollusca</i>
SMB 7.5-2	JUNE	<i>Glycera capitata</i> 15.0 <i>Spiophanes</i> 14.0 <i>Prionospio</i> 8.7 <i>Lumbrinereis</i> 7.7 <i>Onuphis</i> 5.3 <i>Tharyx</i> 4.8 <i>Terebellidae</i> 4.8 <i>Cistena californiensis</i> 4.3 <i>Cossura brueni</i> 3.9	<i>Phoxocephalidae</i> 22.2 <i>Ampelisca</i> 16.7 <i>Callianassidae</i> 16.7 <i>Lepodomorpha</i> 13.0 <i>Cylindroleberidae</i> 5.6 <i>Photis</i> 3.7 <i>Corophidae</i> 3.7 <i>Byblis</i> 2.8	<i>Parvilucina</i> 26.5 <i>Volvulella</i> 26.5 <i>Axinopsida</i> 11.8 <i>Tellina</i> 8.8 <i>Mysella</i> 5.9 <i>Acteocina</i> 5.9
	DEC	<i>Maldanidae</i> 12.3 <i>Prionospio</i> 10.4 <i>Spiophanes</i> 9.6 <i>C. californiensis</i> 6.9 <i>Lumbrinereis</i> 5.0 <i>Phyllodocidae</i> 4.2 <i>Aricidea</i> 3.5 <i>Heteromastus</i> 3.1 <i>Nothria elegans</i> 3.1	<i>Ampelisca</i> 41.7 <i>Phoxocephalidae</i> 10.4 <i>Callianassidae</i> 10.4 <i>Corophidae</i> 7.8 <i>Photis</i> 5.2 <i>Byblis</i> 4.3 <i>Listriella</i> 2.6 <i>Pinnixa</i> 2.6	<i>Axinopsida</i> 34.9 <i>Parvilucina</i> 33.9 <i>Volvulella</i> 11.9 <i>Tellina</i> 6.4 <i>Mysella</i> 2.8
SMB 6.4	JUNE	<i>Spiophanes</i> 28.3 <i>C. californiensis</i> 13.0 <i>Prionospio</i> 12.6 <i>Cirratulidae</i> 10.3 <i>Capitellidae</i> 10.3 <i>Euclymene delineata</i> 5.8	<i>Euphilomedes</i> 87.3 <i>Phoxocephalidae</i> 2.7 <i>Ampelisca</i> 2.4	<i>Parvilucina</i> 78.2 <i>Axinopsida</i> 11.6 <i>Tellina</i> 2.7 <i>Thyasira</i> 2.5 <i>Mysella</i> 1.8
	DEC	one individual collected	<i>Euphilomedes</i> 88.6 <i>Phoxocephalidae</i> 4.1 <i>Ampelisca</i> 2.4	<i>Parvilucina</i> 73.7 <i>Axinopsida</i> 12.6 <i>Tellina</i> 4.9 <i>Thyasira</i> 1.9
SMB 7-3	JUNE	<i>Capitella capitata</i> 87.8 <i>Chloeia</i> 2.9 <i>Spiophanes</i> 2.2	<i>Euphilomedes</i> 90.1 <i>Cylindroleberidae</i> 2.7 <i>Pinnixa</i> 2.7	<i>Parvilucina</i> 36.4 <i>Bittium</i> 22.2 <i>Mysella</i> 18.9 <i>Axinopsida</i> 8.7 <i>Tellina</i> 6.9 <i>Macoma carlottensis</i> 4.7
	DEC	<i>C. capitata</i> 87.2 <i>C. californiensis</i> 4.7 <i>Glycera capitata</i> 2.0 <i>Notomastus</i> 2.0	<i>Euphilomedes</i> 97.6	<i>Parvilucina</i> 61.5 <i>Tellina</i> 13.8 <i>Mysella</i> 12.3 <i>Axinopsida</i> 3.1 <i>M. carlottensis</i> 3.1
PVS 4.5-1	JUNE	<i>C. capitata</i> 40.4 <i>Nereis procera</i> 31.9 <i>Hesionidae</i> 14.9 <i>Notomastus</i> 6.4	five individuals collected	<i>Mysella</i> 39.4 <i>Parvilucina</i> 27.3 <i>Acteocina</i> 18.2
	DEC	<i>C. capitata</i> 94.5 <i>Hesionidae</i> 2.1 <i>Nereis</i> 1.4	eight individuals collected	<i>Parvilucina</i> 37.7 <i>Acteocina</i> 20.3 <i>Kurtzia</i> 15.9 <i>Mysella</i> 11.6 <i>Cylichia</i> 8.7
PVS 7.3	JUNE	<i>C. capitata</i> 89.1 <i>Dorvilleidae</i> 5.5 <i>Nereis</i> 4.0	two individuals collected	<i>Mysella</i> 30.8 <i>Parvilucina</i> 23.1 <i>Kurtzia</i> 23.1
	DEC	<i>C. capitata</i> 89.4 <i>Dorvilleidae</i> 5.2	absent	<i>Parvilucina</i> 53.8 <i>Mysella</i> 15.4 <i>Nudibranchia</i> 15.4

TABLE 4. Summary of Otter Trawl Catches in June (J) and December (D) in Santa Monica Bay (SMB) and on the Palos Verdes Shelf (PVS). Percent Similarity is the Similarity Between June and December Samples.

Station Month	SMB 7.5-2		SMB 6-4		SMB 7-3		PVS 4.5-1		PVS 7-3	
	J	D	J	D	J	D	J	D	J	D
Number of individuals	614	417	289	343	31	185	114	68	88	139
Number of species	20	14	15	14	7	17	7	7	8	11
Diversity	.928	.532	.808	.859	.704	.999	.533	.644	.419	.681
Percent similarity	47.1		42.7		36.4		65.8		71.0	

The composition of the fish assemblage near the wastewater outfalls also changed over relatively short distances. Fish abundance, diversity, and species richness decreased, and the similarity between seasonal collections increased with increasing wastewater effects. Similar patterns were reported for the same area by Allen (1977) and Mearns (1979), and the diversity and similarity findings, though not significant, are in general agreement with Bechtel and Copeland (1970) and Haedrich (1975).

We suggest that changes in the composition of the benthic fish assemblages between sites are the result of changes in the composition of the infauna. Five of the eight species examined for food habits (longspine combfish, yellowchin sculpin, California tonguefish, speckled sanddab, and hornyhead turbot) accounted for a mean of 62% (SD = 14, N = 6) of the catches in SMB but only 2% (SD = 1, N = 4) of the catches on PVS. The total catch of these species in a 10 minute trawl declined from a mean of 205 (SD = 158, N = 6) in SMB to 2 (SD = 1, N = 4) on PVS. Carlisle (1969) also found that abundance of the dominant species in SMB (speckled sanddab, yellowchin sculpin, and California tonguefish) was greater at three stations away from the 8.3 km outfall when compared to three stations close to the outfall.

Longspine combfish, yellowchin sculpin, California tonguefish, and speckled sanddab fed predominately on benthic, epibenthic, and nektonic crustaceans (Table 5), animals that were rare or absent at stations strongly affected by wastewater discharge (Table 3). Several studies demonstrated that yellowchin sculpin (Allen 1982), California tonguefish (Telders 1981), and longspine combfish (Hume, Gunnerson and Imel 1962; Allen 1982) consume polychaetes. However, some of the specimens examined in these studies were collected on the Palos Verdes shelf or in Santa Monica Bay, large portions of which are affected by wastewater discharges. Johnson and Adams (1970) showed that the diets of longspine combfish (N = 104) collected between Point Hueneme and Santa Barbara were dominated by crustaceans, but that polychaetes occurred in about 20% of the stomachs.

The hornyhead turbot fed primarily on spionid and ampharetid polychaetes (Table 5) that were rare or absent at stations strongly affected by wastewater discharge (Table 3). Allen (1982) also found that spionids and ampharetids dominated the diets of hornyhead turbot.

The remaining species examined for food habits (English sole, Pacific sanddab, and Dover sole) accounted for a mean of 14% (SD = 11, N = 4) of fishes captured in SMB and 54% (SD = 32, N = 4) of the fishes captured on PVS. Total catch of these fishes increased from a mean of 39 (SD = 28, N = 6) in SMB to 57 (SD = 38, N = 4) on PVS; the difference is not significant (Mann-Whitney U-test, $p = .305$). The proportion of polychaetes in English sole stomachs increased and the proportion of pelecypods and crustaceans decreased from SMB to PVS (Table 5). The proportion of polychaetes in the diets of Dover

TABLE 5. Stomach Contents of Selected Demersal Fishes. Data Presented as Mean Percent Numbers. Mean Board Standard Length (mm), One Standard Deviation (SD), and Sample Size (n) at Bottom of Table. Mysid/Eupha = Mysidacea/Euphausiacea.—Continued

	Hornyhead turbot				English sole				Pacific sanddab			
	SMB	SMB	PVS	PVS	SMB	SMB	PVS	PVS	SMB	SMB	PVS	PVS
	7.5-2	6-4	7-3	4.5-1	7-3	6-4	7-3	4.5-1	7.5-2	6-4	7-3	4.5-1
Nematoda		5	14		22	28	39			4	4	9
Polychaeta	63	77	79		41	33	61		15	27	34	49
Ampharetidae	23	5	16		23							
Amphictenidae					15	28						
Capitellidae											11	3
Dorvilleidae											8	20
Onuphidae	30	9										
Spionidae		40	47			4				3		
Mollusca					23	19				6		13
Gastropoda					4					6		
Bivalvia					18	19						
Crustacea	36	16			5	18			60	45	63	16
Ostracoda						4			41	20	21	19
Mysid/Eupha											2	
Cumacea												
Tanaidacea												
Isopoda												
Gammaridea	36	13				10	5				20	5
Decapoda												
Osteichthyes												
MM	134	128	140		215	232	151		22	80	94	117
SD	75	29	50		18	34	48		8	37	11	24
N	4	20	10	0	7	16	6	0	20	20	11	19

	Speckled sanddab			Dover sole		
	SMB 7.5-2	SMB 6-4	SMB 7-3	PVS 4.5-1	PVS 7-3	PVS 7-3
Nematoda						
Polychaeta	14	20	21		2	67
Ampharetidae						
Amphictenidae						
Capitellidae			6		9	3
Dorvilleidae					49	38
Onuphidae						
Spionidae						
Mollusca					4	
Gastropoda						
Bivalvia						
Crustacea	76	78	67		93	23
Ostracoda	42	15	23		26	
Mysid/Eupha						
Cumacea		4				18
Tanaidacea						
Isopoda			7		7	
Gammaridea	7	33	30		52	
Decapoda					9	
Osteichthyes	12		4		6	
MM	71	74	85		114	97
SD	6	8	10		16	11
N	20	20	14	0	11	19

sole and Pacific sanddab increased and the proportion of crustaceans decreased from SMB to PVS (Table 5). English and Dover soles are general infaunal predators with preferences for polychaetes (Kravitz *et al.* 1977, Percy and Hancock 1978, Gabriel and Percy 1981, Allen 1982). Percy and Hancock (1978) found a positive correlation between the standing crop of Dover sole and the standing crop of their preferred prey and stated that "... Dover sole are versatile predators, changing their diets opportunistically in response to changes of prey availability." That Pacific sanddab behaved in the same way is surprising; it has a symmetrical mouth that is more adapted to seizing swimming prey (Yazdani 1969) and feeds primarily on pelagic crustaceans and fishes (Kravitz *et al.* 1977; Percy and Hancock 1978).

The results of this study are consistent with the hypothesis that depressions in the abundance of some species of fishes in areas strongly affected by wastewater discharge are caused by lack of suitable prey and increases in the abundance of other species in areas strongly affected by wastewater discharge are caused by an abundance of suitable prey and flexible food habits. Södergren (1976) concluded that the decline in abundance of *Salmo salar* in a river in Sweden receiving heavy metal wastes was largely the result of a decline in abundance of their preferred invertebrate prey which was adversely affected by the metal pollution.

While the data collected in this study are suggestive, several alternative hypotheses cannot be discounted. Changes in the distribution and abundance of some fish species around the outfalls could be the result of: i) habitat modifications (low dissolved oxygen, high hydrogen sulfide and contaminant concentrations) that affect behavior or physiology (e.g. interference with chemoreception, toxic effects, etc.) or, ii) altered biological interactions (changes in abundance of competitors, predators, or preferred prey) that reduce the suitability of the environment.

LITERATURE CITED

- Allen, M. J. 1977. Pollution related alterations of southern California demersal fish communities. *Cal-Neva Wildl. Trans.* 1977:103-107.
- Allen, M. J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. dissertation, Univ. Calif., San Diego, 577 p.
- Allen, M. J. and R. Voglin. 1976. Regional and local variations of bottom fish and invertebrate populations. Pages 217-221 in W. Bascom ed. Coastal Water Research Project Annual Report, 1976. Southern California Coastal Water Research Project, El Segundo.
- Bascom, W. 1978. Life in the bottom. Pages 57-80 in W. Bascom ed. Coastal Water Research Project Annual Report, 1978. Southern California Coastal Water Research Project, El Segundo.
- Bechtel, T. J. and B. J. Copeland. 1970. Fish species diversity indices as indicators of pollution in Galveston Bay, Texas. *Contrib. Mar. Sci.* 15:103-132.
- Boesch, D. F. 1982. Ecosystem consequences of alterations of benthic community structure and function in the New York Bight region. Pages 543-568 in G. F. Mayer ed. *Ecological Stress and the New York Bight: Science and Management*. Estuarine Research Foundation, Columbia, South Carolina.
- Carlisle, J. G., Jr. 1969. Results of a six-year trawl study in an area of heavy waste discharge: Santa Monica Bay, California. *Calif. Fish Game*, 55:26-46.
- Gabriel, W. L. and W. G. Percy. 1981. Feeding selectivity of Dover sole, *Microstomus pacificus*, off Oregon. *Fish. Bull.* 79:749-763.
- Haedrich, R. L. 1975. Diversity and overlap as measures of environmental quality. *Wat. Res.* 9:945-952.
- Hendricks, T. J. 1980. Currents in the Los Angeles area. Pages 243-256 in W. Bascom ed. Coastal Water Research Project Biennial Report, 1979-1980. Southern California Coastal Water Research Project, Long Beach.
- Hume, N. B., C. G. Gunnerson, and C. E. Imel. 1962. Characteristics and effects of Hyperion effluent. *J. Water Pollut. Contr. Fed.* 34:15-35.

- Jan, T. and G. P. Hershelman. 1980. Trace metals in surface sediments of Santa Monica Bay. Pages 171–180 in W. Bascom ed. Coastal Water Research Project Biennial Report, 1979–1980. Southern California Coastal Water Research Project, Long Beach.
- Johnson, C. R. and J. P. Adams. 1970. Biology of *Zaniolepis latipinnis* (Zaniolepidae) in relation to vertical distribution. *Copeia*, (1970) 769–771.
- Kleppel, G. S., J. Q. Word, and J. Roney. 1980. Demersal fish feeding in Santa Monica Bay and off Palos Verdes. Pages 309–318 in W. Bascom ed. Coastal Water Research Project Biennial Report, 1979–1980. Southern California Coastal Research Project, Long Beach.
- Kravitz, M. J., W. G. Pearcy, and M. P. Guin. 1977. Food of five species of co-occurring flatfishes on Oregon's continental shelf. *Fish. Bull.* 74:984–990.
- Mearns, A. J. 1973. Southern California's inshore demersal fishes: Diversity, distribution and disease as responses to environmental quality. *Calif. Coop. Oceanic Fish. Investig. Repts.* 17:141–148.
- Mearns, A. J. 1979. Responses of coastal fishes and invertebrates to wastewater discharges. *Prog. Wat. Tech.* 4:19–32.
- Mearns, A. J. 1981. Effects of municipal discharges on open coastal ecosystems. Pages 25–66 in P. A. Geyer ed. *Man and environmental pollution*. Elsevier, Amsterdam.
- Pearcy, W. G. and D. Hancock. 1978. Feeding habits of Dover sole, *Microstomus pacificus*; rex sole, *Glyptocephalus zachirus*; slender sole, *Lyposetta exilis*; and Pacific sanddab, *Citharichthys sordidus*, in a region of diverse sediments and bathymetry off Oregon. *Fish. Bull.* 76:641–651.
- Pearson, T. H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. mar. Biol. Rev.* 16:299–311.
- Schafer, H. A. 1982. Characteristics of municipal wastewater. Pages 11–15 in W. Bascom ed. Coastal Water Research Project Biennial Report, 1981–1982. Southern California Coastal Water Research Project, Long Beach.
- Södergren, S. 1976. Ecological effects of heavy metal discharge in a salmon river. Rept. Instit. Freshwater Research Drottningholm. No. 55:91–131.
- Telders, E. L. 1981. Feeding periodicity and diet of the California tonguefish, *Symphurus atricauda* (Pisces: Cynoglossidae). Thesis, Calif. State Univ., Long Beach, 49 p.
- Tillman, D. C. and R. D. Bargman. 1973. Report on waste discharges to the ocean, Part 1. Dept. Publ. Works, City of Los Angeles, 336 p.
- Word, J. Q. and A. J. Mearns. 1979. 60-meter control survey off southern California. Southern California Coastal Water Research Project, Long Beach. Tech. Mem. 229., 58 p.
- Yazadani, G. M. 1969. Adaptations in the jaws of flatfish (Pleuronectiformes). *J. Zool. (Lond.)* 149:181–222.

UTILIZATION OF NATURAL AND MAN-MADE HABITATS¹ BY THE SALT MARSH SONG SPARROW, *MELOSPIZA MELODIA SAMUELIS* (BAIRD)

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Territorial configuration and seasonal densities for the salt marsh song sparrow, *Melospiza melodia samuelis* (Baird), were estimated for natural tidal waterways and man-made mosquito control ditches in Petaluma Marsh, Sonoma County, California. Territory size and interterritory distance were negatively correlated with plant spatial diversity ($p < 0.006$) and plant cover height ($p < 0.025$), but nesting-pair density was positively correlated with these vegetation parameters ($p < 0.004$). Numbers of song sparrows during post-nesting season were positively correlated with plant cover height ($p < 0.042$) and percent cover for coyote brush, *Baccharis pilularis* D.C. ($p < 0.024$).

Nesting-pair density was generally greater along natural waterways than along ditches because natural habitats contained adequate nesting and springtime food resources in less space, resulting in smaller territories that were closer together. Non-territorial adult and dispersing juvenile song sparrows were less attracted to ditches than to natural waterways because ditched habitat contained less summer-time food resources and fewer roosts. Although mosquito control ditches are not preferred habitat, they have increased the total numbers of salt marsh song sparrows in Petaluma Marsh.

INTRODUCTION

Man-made ditches have been used since the beginning of this century to control populations of mosquitoes in North American tidal marshes (Provost 1977, Resh and Balling 1983). Ditches connect natural tidal waterways to shallow depressions in the marsh surface and control mosquito populations by either draining larval habitat or increasing its accessibility for predatory fish (Balling, Stoehr, and Resh 1980).

Since the addition of ditches can influence plant community composition and vegetative structure (Daigh, MacCreary, and Stearns 1938; Miller and Egler 1950; Travis, Bradley, and McDuffie 1954; Balling and Resh 1983), we anticipated that song sparrow distribution might also be affected. Throughout their range, song sparrows occupy habitats typified by a dense or well-developed understory that conceals bare ground and is near to water (Marshall 1948a). Furthermore, habitat preference and territory size has been related to vegetation type and structure for upland subspecies of song sparrows (Nice 1937, 1943; Beer, Frenzel, and Hansen 1956; Suthers 1960; Dickerman 1963; Tompa 1964). Although little information is available about the effects of ditching on passerine bird species (Burger, Shisler, and Lesser 1979), Post (1974), in a study of the seaside sparrow, *Ammonspiza maritima* (Wilson), in New York salt marshes, found that ditched areas contained fewer nesting pairs and larger territories than unditched areas. He related these differences to the influence of ditching on plant community composition.

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The salt marsh song sparrow, *Melospiza melodia samuelis* (Baird), is one of three subspecies of song sparrows that inhabit salt or brackish water marshes in the San Francisco Bay Area. These subspecies have been distinguished based upon their morphology and habitat preferences (Marshall 1948a, b), and blood group frequencies (Ferrel 1966). The subspecies are distributed allopatrically, with *M. m. samuelis* inhabiting salt marshes around northern San Francisco Bay (Marshall 1948a). In terms of numbers and biomass, the salt marsh song sparrow dominates the resident avifauna of these marshlands.

Our preliminary investigations indicated that salt marsh song sparrows use ditches as nesting and foraging habitat. Subsequently, we compared ditches to natural habitats by examining territory size and spacing, chronology of territoriality, seasonal bird densities, nest site availability, and relationships between these parameters and vegetative cover height, plant spatial diversity (i.e. complexity of the floral mosaic, sensu Pielou 1975), and percent cover of dominant plant species.

SITE DESCRIPTION

This study was conducted from summer, 1980, to autumn, 1981, at Petaluma Marsh, a 1,145 ha salt marsh located along the Petaluma River, 10 km north of San Francisco Bay, California (Figure 1, A–C). The marsh was extensively ditched between 1969 and 1976.

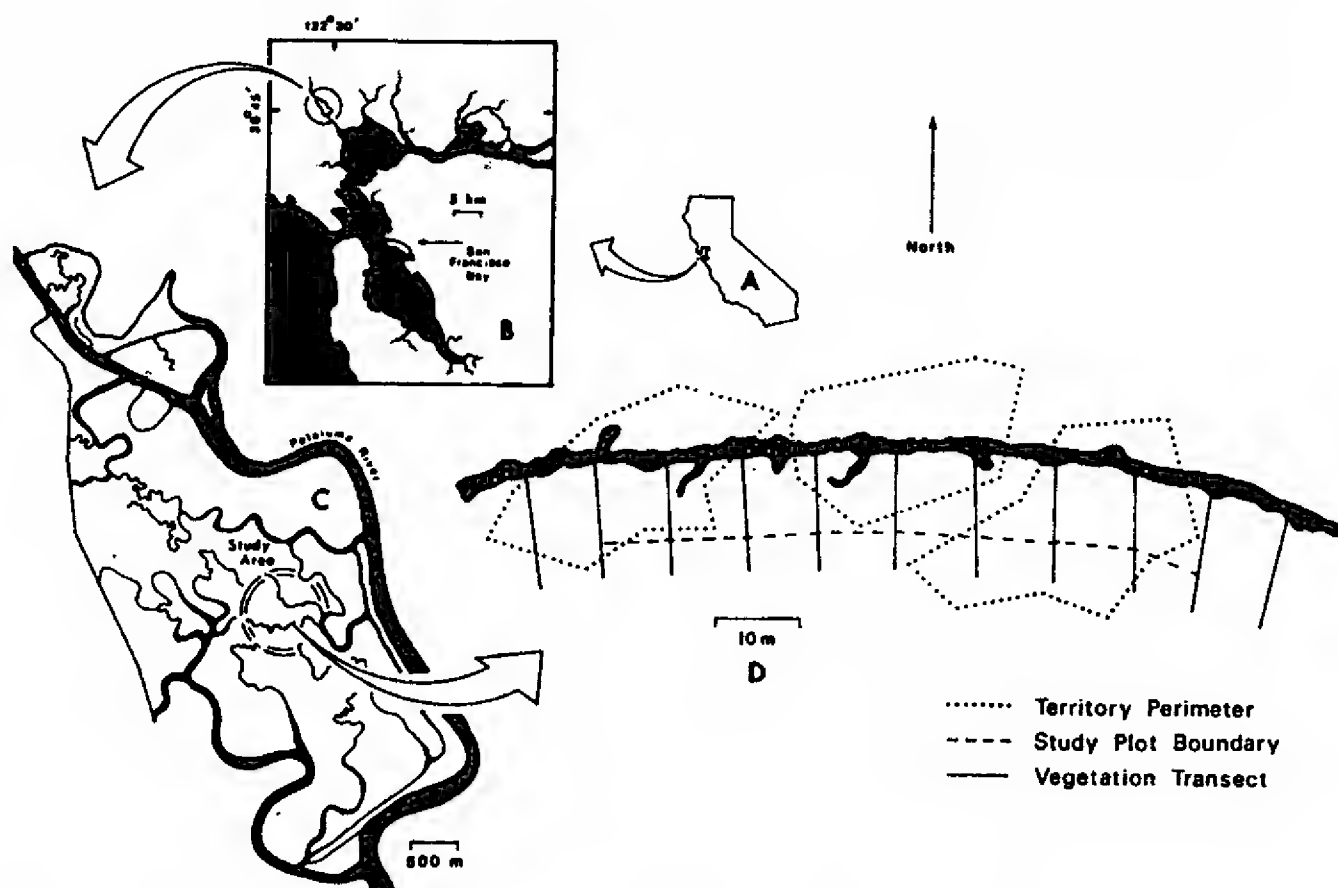


FIGURE 1. Study area location (A–C) and diagrammatic example of a natural channel study plot (D) that shows vegetation transects and three Song Sparrow territories.

The vegetation of the marsh is dominated by pickleweed, *Salicornia virginica* L., but also includes: cordgrass, *Spartina foliosa* Trin.; salt grass, *Distichlis spicata* L.; *Jaumea carnosa* (Less.) Grey; *Frankenia grandifolia* Cham. and Schlect; gum-

plant, *Grindelia humilis* Hook. and Arm.; and coyote brush, *Baccharis pilularis* D.C. The latter two species are the tallest features of the vegetative cover and essentially are restricted to natural levees and spoil piles that result from ditching.

For the purposes of this study, four types of habitat were distinguished based upon their physiographic characteristics. (i) *Sloughs* range in width from about 2 to 15 m, are wider than they are deep, and are open to the river at both ends. (ii) *Natural channels* range in width from about 0.5 to 3 m, are deeper than they are wide, and originate in dendritic form on the marsh surface. (iii) Man-made ditches, often termed *mosquito control recirculation ditches*, which resemble the upper reaches of natural channels, are about 45 cm wide and 60 cm deep. Ditches can be interconnected and confluent with either natural channels or sloughs. (iv) Areas that are at least 10 m away from any waterways are referred to as *open marshland*. Marsh physiography relates to other habitat parameters, including flora characteristics that differ among the habitat types (see results), but were not used as *a priori* criteria for the selection of study plots.

METHODS

Plot Selection

Study plots were confined to a 80 ha central portion of the marsh that is uniformly influenced by weather and tides and was ditched in 1975. For the 1980 studies, three replicate plots for each type of waterway and for open marshland were randomly selected from a total of 15 possible plots for each habitat type. For the 1981 studies, the open marshland plots were eliminated because they rarely contained song sparrows (see results) and four new replicates of each waterway type were selected. All plots were 10 m wide and extended 100 m through open marshland or along one side of a waterway. Our study plot width is approximately equal to that used by Johnston (1956a), who determined that most song sparrow activity was confined to an area within 9 m of a waterway. Also, waterway habitat tends to grade into open marshland by the 10 m distance (Balling and Resh 1983).

Territory Size

Territory boundaries were delineated by constructing composite maps of the movements of singing males. On diagrams of the plots, straight lines were drawn that connected the outermost sightings of each male to form polygons representing territorial areas. The sizes of the areas were determined with a planimeter. The number of sightings necessary to map a territory ranged from 7 to 30, and was generally highest for natural channels. We found that individual males could be followed readily, and that provocation by observers did not result in either an increase or decrease in apparent size of territories. A territory was mapped if any portion of it occurred within a study plot, and flights across waterways were included in estimates of territory size. Three to four pairs of observers worked simultaneously to map territories on each date.

Mapping was done during flood tide on the mornings of 7 and 14 February and 7 March, 1981. These dates corresponded to the period of springtime territory establishment and nest site selection reported for *M. m. samuelis* by Johnston (1956a). In addition, territorial males were counted at each plot generally biweekly from April through June and August through October, 1981.

Territory Spacing

A four-step procedure was used to determine the mean distance between neighboring territories. First, each territory in its apparent polygonal form was assumed to be a planar region with a uniform density of bird activity and as such was plotted onto a cartesian coordinate system. Thus, the average x- and y-values for the ordered pairs that delimited the perimeter of a territory determined its center. Second, the distances between the centers of neighboring territories were measured. Third, the territories of known area were regarded as circles and their radii were calculated; each radius then represented the mean distance between the center of a territory and its perimeter. Fourth, the radii of each pair of neighboring territories were subtracted from the distance between their centers. The latter two steps provided an unbiased estimate of either the distance between adjacent boundaries of neighboring territories or the extent of their overlap, regardless of their convolutions.

Density of Nesting Pairs

We assumed that each territory represented a single pair of nesting song sparrows. Therefore, nesting-pair density was estimated by summing the fractions of territories occurring within each plot and equating the sums to the numbers of pairs that the plots actually supported, either entirely or in part.

Density of Birds During Post-Nesting Season

Total counts of song sparrows were made on 13 and 18 July, 1980 and 5 and 30 June, 1981. These dates generally correspond to the annual cessation of springtime territorial activity and maximum dispersal by juveniles (Johnston 1956a). For each count, a pair of workers moved unidirectionally through a study plot for 30 min, noting all birds flushed. Counts were conducted during slack high tide, when birds could not remain hidden within waterways. No birds were counted more than once, and reconnaissance immediately following counts indicated that very few birds ($< 1\%$ of the total number at a plot) were uncounted on any given date.

Vegetation

Percent cover for the five dominant cover types occurring along waterways (*Salicornia*, *Jaumea*, *Frankenia*, *Baccharis*, and unconcealed ground), plant cover height, and plant spatial diversity were determined for the 1981 study plots. The heights and types of cover were recorded at 1 m intervals along eleven line-transects, 15 m long and 12 m apart, that were established perpendicular to the waterway at each plot (Figure 1D). Percent cover was visually estimated for ten 18 m² non-overlapping subregions of each 180 m² area between transects. Because data were collected throughout the plots, information could be analyzed separately for each mapped territory and its immediate surroundings. All data were collected during mid-April, between the measurements of densities of breeding pairs and non-nesting birds.

Prior to the inception of the 1981 breeding season, distances from ground level to the plant canopy top and the suspended litter layer were measured at 60 randomly selected points throughout the study area. Suspended litter refers to plant debris that is deposited into the vegetation during canopy senescence and is suspended above ground level by plant architecture.

Statistical Treatment

One-way analysis of variance and t-tests were used to test the hypotheses that the habitat types did not differ with regard to mean territory size, interterritory distance, or seasonal bird densities. Relationships between these parameters and vegetation characteristics were examined with simple linear regression. The analyses of variance and regression models were assessed at a significance level of 0.05. Bonferroni's Inequality was used to maintain an overall error rate of 0.05 during multiple t-test comparisons.

RESULTS AND DISCUSSION

Chronology of Territoriality

Throughout our mapping efforts, no decrease in numbers of territories was observed at any study plot. Between 7 and 14 February, territories increased in number along ditches and sloughs by 60 and 43%, respectively. Along natural channels, the number of territories did not change. Between 14 February and 7 March, numbers of territories apparently remained the same for all three types of habitats; in late May, the number of territories began to decrease. Therefore, we assume that the final territory maps for 1981 (7 March) represent the peak density of nesting pairs for that year, and that formation of territories was completed first at natural channels and last at ditches.

Territoriality for the 1981 breeding season was evident from February through June, but was most apparent in March and April. During autumn, we observed a resurgence of territorial singing. However, at that time most singing males shared habitat with three or more other song sparrows. Therefore, we expect that autumnal singing does not represent establishment of true territories. Similar findings were reported by Johnston (1956a), who suggested that territorial display in autumn only serves to terminate dispersal by young salt marsh song sparrows.

Territory Size

Definitions

Previous workers have categorized song sparrow territories according to their inclusion or omission of foraging regions. Tompa (1964) distinguished between defended and utilized areas, because neighboring birds fed together in places distant from their nesting grounds. He also noted that such semi-colonial behavior was unusual for the species. Nice (1943) defined Type A territories as inclusive of foraging areas and found that, for song sparrows, other territory types were uncommon.

At Petaluma Marsh, territories generally correspond to the Type A category defined by Nice (1943). Johnston (1956a) reported that most salt marsh song sparrow activities were confined to defended areas. This does not preclude the displacement of males, selection of new mates by females between clutches, or the occasional travel by birds to and from locations that are beyond territorial boundaries. However, we observed that the foraging movements of mated pairs were mainly restricted to regions demarcated by territorial display.

Spatial Variability

At the time of apparent peak nesting-pair density (7 March), territory size differed significantly among the three types of waterways. Territories along

ditches were nearly twice as large as those along natural channels, and intermediate size territories occurred along sloughs (Table 1). Elimination of waterway surfaces from the calculation of territorial areas did not reduce the variance in territory size for any waterway type.

Territory size was negatively correlated with plant spatial diversity (Table 2), which probably indicates a relationship between spatial diversity and the availability of food. Since song sparrows generally are not restricted in food selection to any particular kind of insect, seed, or flower (Tompa 1964), an increase in kinds of food should increase its availability. In the spring, when omnivorous adult salt marsh song sparrows primarily feed invertebrates to their nestlings (Marshal 1948a), arthropod diversity at Petaluma Marsh was found to be higher along natural channels than along ditches (Balling and Resh 1982). Furthermore, insect diversity generally is higher in more spatially diverse habitats (Murdoch, Evans, and Peterson 1972). Finally, territory size has been shown to decrease with increased food availability for passerines (Morse 1976).

The negative correlation between territory size and mean cover height (Table 2) also might relate to food availability (i.e. an increase in cover height might be functionally equivalent to an increase in insect habitat). Perhaps more importantly, this statistical correlation probably reflects a relationship between cover height and nest site availability. According to Johnston (1956b), salt marsh song sparrow nests must be located high enough above ground level to avoid the seasonally high tides of late May and June, which are the major causes of egg and nestling mortality, and yet be deep enough within the vegetative cover to escape predation by raptors. Based upon empirical measurements of tides in our study area, we have determined that nests must be located at least 20 cm above the ground to avoid inundation by the higher high tides of late spring. Since the nests are about 5 cm tall, they are safe only if the suspended litter layer, which serves to conceal the nests, is at least 25 cm above the ground. Examination of the relationship between canopy height and position of suspended litter reveals that the vegetative cover must be at least 54 cm tall to afford safe nest sites (Figure 2). Comparison of this height (i.e. 54 cm) and the canopy height at different distances away from the three types of waterways indicates that safe nest sites potentially occur throughout all the natural waterway study plots (NC and S, Figure 3), but are probably restricted to the immediate margins along ditches (D, Figure 3). The problem of nest site scarcity along ditches is compounded by the number of sites that are required by each nesting pair during a breeding season. Most pairs produce two to three clutches annually, each of which usually requires a separate nest site. Also, nest sites are not reused each year, even though the same territories are often re-established (Johnston 1956b). Therefore, since all nesting occurs within territories, they tend to be larger in areas of poor nesting habitat.

Song sparrow territory size has been shown to increase with numbers of species of competitors, presumably because they reduce food availability (Cody 1974). However, at Petaluma Marsh, territories were smallest along natural channels, where competitor species richness was relatively high. This suggests that food is sufficiently available at natural channels to mask any effects of competitors on territory size.

TABLE 1. Comparisons of Natural Channel (NC), Slough (S), and Ditch (D) Habitats Based Upon (a) Mean Territory Size, (b) Mean Interterritory Distance, and (c) Mean-Density of Nesting Pairs for 7 March, 1981; * Indicates Significant p-Values for t-Tests With The Procedure-Wise Significance Level = 0.0083.

Waterway type	(a)	(b)	(c)	t-test	p-values	
	$\bar{x}$ territory size (m^2) (n)	$\bar{x}$ interterritory distance (m) (n)	$\bar{x}$ nesting-pair density (n/ha) (n)		(a)	(b) (c)
NC	387 $\pm$ 62.2 (11)	3.6 $\pm$ 5.4 (7)	24.5 $\pm$ 4.0 (4)	NC vs S	0.002*	0.082 0.0086
S	498 $\pm$ 90.4 (10)	11.2 $\pm$ 5.4 (6)	15.4 $\pm$ 4.1 (4)	S vs D	0.001*	0.021 0.005*
D	644 $\pm$ 88.2 (8)	24.6 $\pm$ 12.3 (4)	5.4 $\pm$ 0.8 (4)	D vs NC	<0.001*	<0.001* <0.001*

TABLE 2. Correlation Coefficients (r) And Their Significance (p) for Relationships Between Vegetative Characteristics and Mean Territory Size, Interterritory Distance, and Seasonal Bird Densities. CV Refers to the Coefficient of Variation. Data for Nesting-Pair Density Pertain to 7 March 1981; * Indicates Significant Correlation at $\alpha = 0.05$.

Vegetative characteristics	Territory size		$\bar{x}$ Interterritory distance		Density of nesting pairs		5 June 1981 Density (post-nesting season)		30 June 1981 Density (post-nesting season)	
	r	p	r	p	r	p	r	p	r	p
plant spatial diversity	-0.88	0.001*	-0.70	0.006*	+0.92	0.001*	+0.46	0.077	+0.44	0.076
mean cover height	-0.76	0.001*	-0.56	0.025*	+0.71	0.004*	+0.62	0.016*	+0.52	0.042*
cover height CV	-0.28	0.071	-0.13	0.34	+0.46	0.066	+0.45	0.071	+0.38	0.11
% <i>Salicornia</i>	+0.34	0.054	+0.26	0.21	-0.37	0.12	-0.74	0.003*	-0.46	0.066
% <i>Jaumea</i>	+0.14	0.24	+0.14	0.33	+0.32	0.16	-0.22	0.246	+0.09	0.39
% <i>Frankenia</i>	+0.01	0.48	-0.33	0.15	+0.43	0.081	+0.46	0.066	+0.33	0.15
% <i>Baccharis</i>	-0.23	0.12	-0.36	-0.12	+0.21	0.25	+0.72	0.004*	+0.58	0.024*
% bare ground	+0.002	0.50	+0.15	0.32	-0.22	0.24	+0.10	0.62	-0.18	0.28
n	29		12		12		12		12	

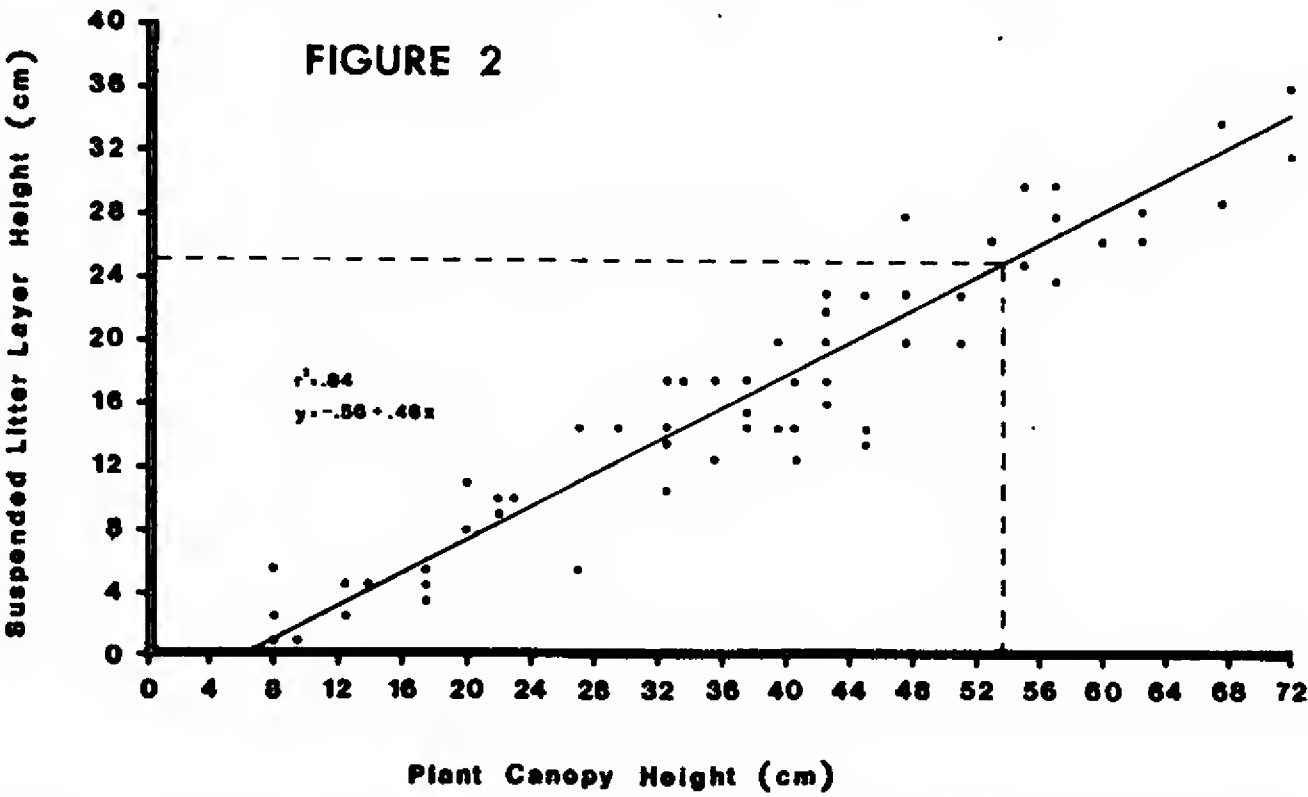


FIGURE 2. Relationship between plant canopy and litter layer heights, with dashed lines indicating the heights required for safe nesting.

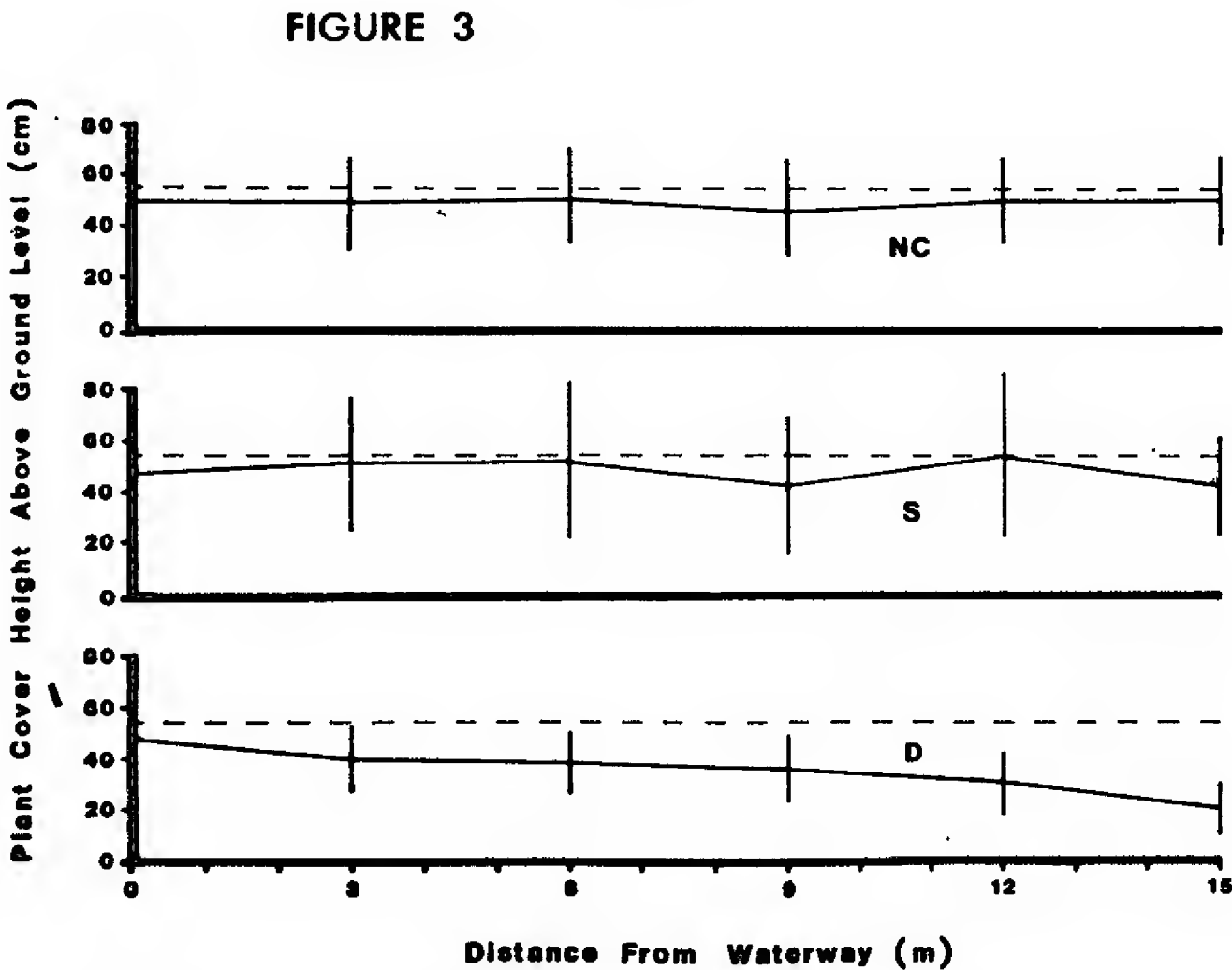


FIGURE 3. Mean height of vegetative cover at six distances from each of three waterway types: natural channels (NC), sloughs (S), and ditches (D). Broken lines represent height of plant canopy necessary for safe nesting (54 cm, see Fig. 2). Vertical bars (including a white bar at zero distance) represent plant height variability (± 1 SD).

Compared to the territories of other song sparrow subspecies, those of *M. m. samuelis* are intermediate in size. Territories along natural waterways were similar in size to those measured by Johnston (1956a), whereas territories along ditches were larger (Table 3).

TABLE 3. Comparison of Territory Size For Various Subspecies of Song Sparrows, Adapted From Tompa (1964). Present Study is Represented By Values for 7 March, 1981; * Indicates Year of Peak Density and Minimum Territory Size During Six Year Study; † Indicates Sloughs and Natural Channels Combined.

Locality and habitat	Mean territory size (m ²)	Date	Reference
Canada			
British Columbia			
Mandarte Island	322	1961	Tompa 1964
Mandarte Island	229	1963	Tompa 1964
Halibut Island	ca. 3000	1961-63	Tompa 1964
Ker Island	ca. 1500	1962	Tompa 1964
United States			
Ohio			
gardens and parks	2700	NA	Nice 1943
Minnesota	1902	NA	Suthers 1960
California			
unditched salt marsh	416*†	1953	Johnston 1956b
ditched salt marsh			
natural waterways	438†	1981	present study
man-made ditches	644	1981	present study

Temporal Variability

For each waterway type, the mean size of occupied territories decreased during the 1981 breeding season (Figure 4A), even after all territories were established. These decreases were synchronous and probably represented a concentration of activity by mated pairs in the immediate vicinity of nest sites, as would be required for egg incubation and the protection and feeding of nestlings. Also, the period of reduction in territory size corresponds to increases in arthropod biomass and diversity along waterways (Balling and Resh 1982) and numbers and kinds of plants in bloom. Therefore, the need for relatively long foraging trips might be reduced during spring by increases in food availability.

Temporal variation in territory size was significantly less for sloughs and natural channels than for ditches ($p < 0.001$). Since territory size and resource availability appear to be closely related (Figure 4A and text above), the temporal variation of one parameter probably reflects that of the other. Thus, like territory size, the availability of resources probably varies less within natural habitats. Indeed, production of seed at ditches is mainly restricted to *Salicornia*, which blooms late in the breeding season, whereas natural waterways support substantial amounts of *Jaumea*, *Frankenia*, and *Baccharis*, which together represent almost year-round seed production.

Territory Spacing

During the 1981 breeding season, increases in interterritorial distance (Figure 4B) generally were opposite and proportional to decreases in territory size (Figure 4A). For territories along natural channels and sloughs, the mean distance between territory centers (Figure 4C) was relatively constant. This indicates that contractions of territories in natural habitat were concentric around

territorial centers that had fixed locations. Therefore, we infer that territorial arrangement is more stable within natural habitat than along ditches.

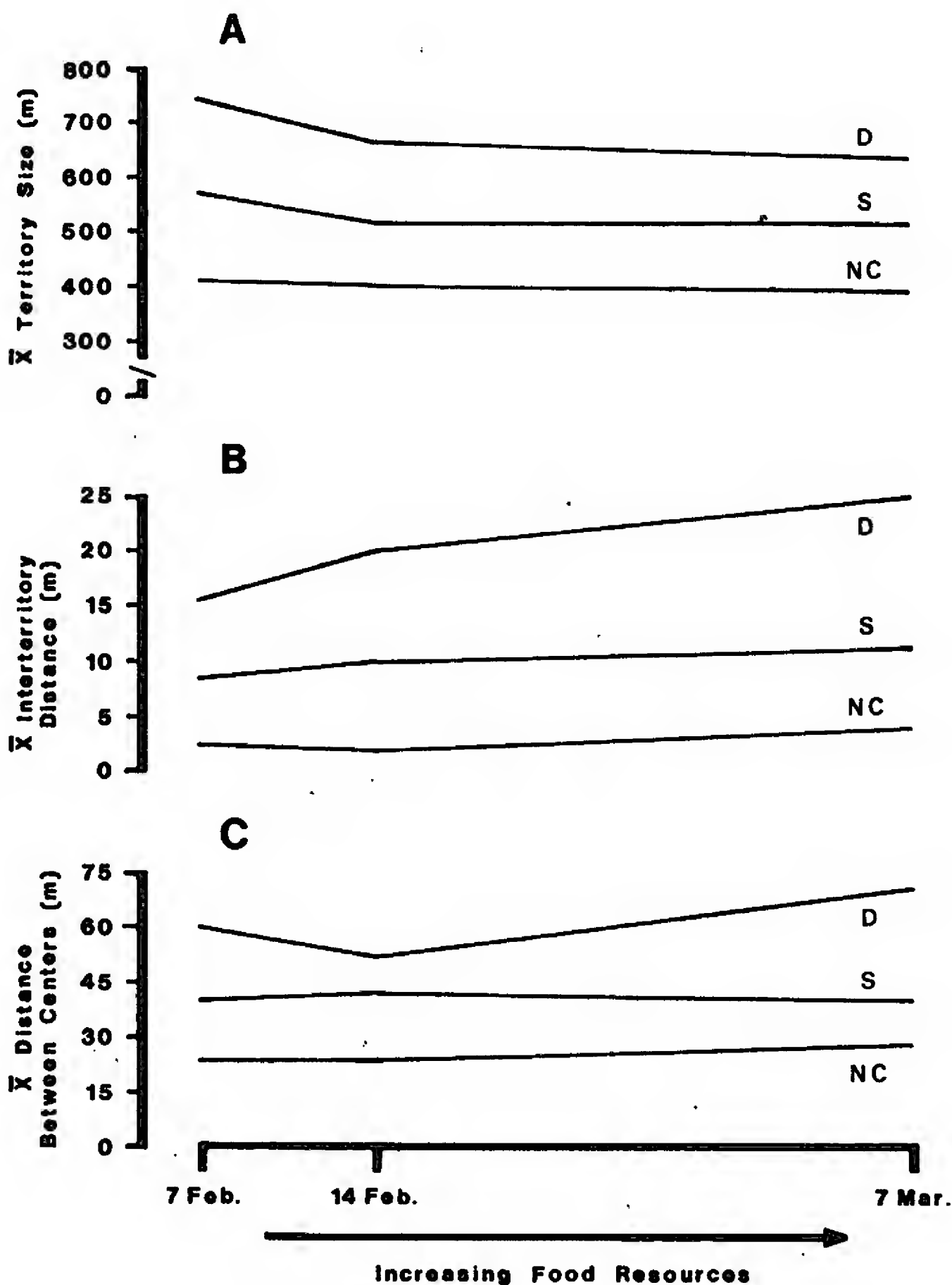


FIGURE 4. Schematic demonstration of the interrelations between (A) mean territory size, (B) mean interterritory distance, and (C) mean distance between centers of neighboring territories for ditched (D), slough (S), and natural channel (NC) habitats.

Interterritory distance may be a function of resource availability. Since male salt marsh song sparrows establish permanent territories (Johnston 1956a), changes in territory size that are in response to changing resources can serve as an iterative adjustment of territorial centers, in order that increases in territory size do not cause territorial overlap and strife. In effect, the spaces between territories may serve as reserves of habitat that can be apportioned among territories during periods of resource depletion (Collins and Resh, unpub. data). Given this mechanism, the occurrence of relatively short interterritorial distances in natural habitat (Table 1) and the negative correlations between interterritorial distance and both plant cover height and spatial diversity (Table 2), indicate that relatively small areas of natural habitat are required to reserve adequate resources.

Along each type of waterway, territories tended to be larger than the spaces between them. In order to combine spaces to form territories, immigrant males would have to initiate consecutive displacement of nesting pairs. More likely, when a male ventures into an interterritorial space and attempts to increase his territory to meet minimum resource requirements, he is either expelled or usurps the domain of a neighbor. Since territories were established last at ditches, they might have been occupied by males evicted from natural channels and sloughs.

Density of Nesting Pairs

Nesting-pair density differed significantly among the three types of habitat ($p = 0.007$), with greater densities occurring along the natural waterways (Table 1). These differences resulted from the combined influences of territory size and interterritory distance. For example, densities were most similar for sloughs and natural channels, sites where the differences in interterritory distance and territory size were least significant; densities were most different for natural channels and ditches, sites where the differences in interterritory distance and territory size were most significant (Table 1). Therefore, the positive correlations between nesting-pair density and both plant cover height and spatial diversity (Table 2) resulted from the correlation among these vegetation parameters and both territory size and spacing.

Annual changes in the total number of breeding males may influence differences in nesting-pair density among habitat types. In natural habitat, Johnston (1956b) found that territory size decreased as population size increased. This suggests that reductions in territory size can accommodate an annual increase in number of males. However, since territorial configuration appears to be more stable in preferred habitat, a change in total population size is more likely to affect the density of birds occupying habitats that are not preferred. Therefore, annual variation in nesting-pair density may be less for natural than for ditched habitat.

Our overall estimate of nesting-pair density for natural waterways is similar to that reported by Johnston (1956b) for an unditched salt marsh (Table 4). This indicates that the process of ditching generally has not affected the carrying capacity of the natural habitats.

Density of Birds During Post-Nesting Season

The estimates of non-nesting song sparrow density resulted from combined counts of adult and juvenile birds and cannot be used to distinguish any influences of habitat type on natality or fledgling survival. However, because the

counts were made during the dispersal phase of the salt marsh song sparrow annual cycle, they can reflect the relative attractiveness of different waterway types to both juveniles and non-territorial adults. In this context, dispersal not only refers to the movement of young birds from their places of birth to eventual breeding sites, but also to the preliminary "exploratory phase" (Tomba 1964), during which young birds move throughout their surroundings and sometimes congregate at places of high food availability. Johnston (1956b) determined the mean dispersal distance (hatch site to breeding site) for salt marsh song sparrows to be 185 m, which would indicate that young birds at Petaluma Marsh can disperse among all four types of habitat.

During our census of non-nesting song sparrows, almost none were observed in open marshland. Also, birds that were observed in such areas were always en route between waterways. The avoidance of open marshland by salt marsh song sparrows undoubtedly relates to a lack of both food and refuge from predation.

TABLE 4. Comparison of Nesting Pair Density For Ditched and Unditched Salt Marsh Song Sparrow Habitats. Present Study (i.e. Ditched Salt Marsh) is Represented By Values For 7 March, 1981. The Value For Unditched Salt Marsh Represents The Period of Peak Density and Minimum Territory Size During Six Year Study by Johnston (1956b).

<i>Habitat</i>	<i>Mean Density of Nesting Pairs (n/ha)</i>
Unditched salt marsh	
natural waterways	24
Ditched salt marsh	
natural waterways	20
Man-made ditches	6

Although densities of non-nesting birds were similar for all three waterway types on each census date, fewer birds were always encountered along ditches than along sloughs or natural channels (Table 5). The number of nesting pairs supported by a plot during the breeding season was not a good predictor of the number of non-nesting birds that the same plot contained during the subsequent period of dispersal. However, non-nesting bird density was positively correlated with mean cover height and percent cover by *Baccharis* (Table 2). During the dispersal period large *Baccharis* plants often contained groups of birds foraging on insects and seeds. This suggests that *Baccharis* provides important roosts and summertime food resources for salt marsh song sparrows.

TABLE 5. Comparisons of Non-nesting Salt Marsh Song Sparrow Densities (number/ha $\pm$ SD) for the 1981 Post Nesting Season at Natural Channels (NC), Sloughs (S), and Ditches (D). Data for Open Marshland (OM) Were Insufficient for Inclusion in Comparisons. No Comparisons Were Statistically Significant ($\alpha = 0.05$). NA Indicates Data Not Available.

<i>Date</i>	<i>NC</i>	<i>S</i>	<i>D</i>	<i>p-value</i>	<i>OM</i>
13 July 1980	66 $\pm$ 20.5	63 $\pm$ 24.9	23 $\pm$ 9.4	0.12	0.0
18 July 1980	60 $\pm$ 14.1	53 $\pm$ 23.6	40 $\pm$ 8.2	0.52	4 $\pm$ 1.8
5 June 1981	85 $\pm$ 36.4	103 $\pm$ 25.8	48 $\pm$ 14.8	0.09	NA
30 July 1981	35 $\pm$ 20.6	43 $\pm$ 10.9	20 $\pm$ 7.1	0.19	NA

CONCLUSIONS

Mosquito control ditches are not preferred habitat for the salt marsh song sparrow, primarily because ditches support shorter and spatially less diverse vegetation than apparently occurs along sloughs and natural channels. However,

ditches do provide additional habitat that has increased the carrying capacity of Petaluma Marsh for salt marsh song sparrows. Examination of recent aerial photographs of the marsh revealed that ditching has increased the amount of habitat along tidal waterways by nearly 300%. Based upon this figure and the average number of territories occurring within 1000 m² of ditched habitat, we estimate that ditching has added more than two thousand salt marsh song sparrow territories to the Petaluma Marsh.

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LITERATURE CITED

- Balling, S.S., T. Stoehr, and V.H. Resh. 1980. The effects of mosquito control recirculation ditches on the fish community of a San Francisco Bay salt marsh. *Calif. Fish Game*, 66: 25-34.
- Balling, S.S., and V.H. Resh. 1982. Arthropod community response to mosquito control recirculation ditches in San Francisco Bay salt marshes. *Environ. Entomol.* 11: 801-808.
- Balling, S.S., and V.H. Resh. 1983. The influence of mosquito control recirculation ditches on plant biomass, production and composition in two San Francisco Bay salt marshes. *Estuarine Coastal Shelf Sci.* 16: 151-161.
- Beer, J.R., L.D. Frenzel, and N. Hansen. 1956. Minimum space requirements of some nesting passerine birds. *Wilson Bull.* 68: 200-209.
- Burger, J., J. Shisler, and F. Lesser. 1979. The effects of marsh management practices, particularly ditching, on nesting birds. *Proc. N.J. Mosq. Exterm. Assoc.* 64: 184-185.
- Cody, M.L. 1974. *Competition and the structure of bird communities*. Princeton University Press, Princeton, N.J. 318 p.
- Daigh, F.C., D. MacCreary, and L.A. Stearns. 1938. Effect of ditching for mosquito control on the pH of marsh soils. *Proc. N.J. Mosq. Exterm. Assoc.* 26: 39-43.
- Dickerman, R.W. 1963. The song sparrows of the Mexican plateau. *Pap. Minn. Mus. Nat. Hist.* 9: 79 p.
- Ferrel, G.T. 1966. Variation in blood group frequencies of song sparrows of the San Francisco Bay region. *Evolution*, 20: 369-382.
- Johnston, R.F. 1956a. Population structure in salt marsh song sparrows. Part I: environment and annual cycle. *Condor*, 58: 22-44.
- . 1956b. Population structure in salt marsh song sparrows. Part II: density, age structure, and maintenance. *Condor*, 58: 254-272.
- Marshall, J.T. 1948a. Ecological races of song sparrows in the San Francisco Bay region. Part I: habitat and abundance. *Condor*, 50: 193-215.
- . 1948b. Ecological races of song sparrows in the San Francisco Bay region. Part II: geographical variation. *Condor*, 50: 233-256.
- Miller, W.R., and F.E. Egler. 1950. Vegetation of the Wequetequock-Pawcatuck tidal-marshes, Connecticut. *Ecol. Monogr.* 20: 143-172.
- Morse, D.H. 1976. Variables affecting the density and territory size of breeding spruce-woods warblers. *Ecology*, 57: 290-301.
- Murdoch, W.W., F.C. Evans, and C.H. Peterson. 1972. Diversity and patterns in plants and insects. *Ecology*, 53: 819-829.
- Nice, M.M. 1937. Studies in the life history of the song sparrow. Part I: a population study of the song sparrow. *Trans. Linn. Soc. N.Y.* 4: 1-247.
- . 1943. Studies in the life history of the song sparrow. Part II: the behavior of the song sparrow and other passerines. *Trans. Linn. Soc. N.Y.* 6: 1-328.
- Pielou, E.C. 1975. *Ecological diversity*. Wiley-Interscience, John Wiley and Sons, N.Y. 165 p.
- Post, W. 1974. Functional analysis of space-related behavior in the Seaside Sparrow. *Ecology*, 55: 564-575.
- Provost, N.W. 1977. Source reduction in salt-marsh mosquito control: past and future. *Mosq. News*, 37: 689-698.
- Resh, V.H. and S.S. Balling. 1983. Tidal circulation alteration for salt marsh mosquito control. *Environ. Manage.* 7: 79-84.
- Suthers, R.A. 1960. Measurement of some lake-shore territories of the song sparrow. *Wilson Bull.* 72: 232-237.
- Tomba, F.S. 1964. Factors determining the numbers of song sparrows, *Melospiza melodia* (Wilson), on Mandarte Island, B.C., Canada. *Acta Zool. Fenn.* 109: 1-68.
- Travis, B.V., G.H. Bradley, and W.C. McDuffie. 1954. The effect of ditching on salt-marsh vegetation in Florida. *Proc. N.J. Mosq. Exterm. Assoc.* 41: 235-244.

NOTES

PUP PRODUCTION, ABUNDANCE, AND BREEDING DISTRIBUTION OF NORTHERN ELEPHANT SEALS ON SAN NICOLAS ISLAND, WINTER 1981

A major breeding colony of northern elephant seals, *Mirounga angustirostris*, occurs on San Nicolas Island, California. Due to commercial hunting, elephant seals were extinct on San Nicolas Island by the end of the 19th century. Subsequent recovery of the population has been well documented (Table 1). Census data collected since 1949 indicate that the colony has been growing rapidly in numbers after breeding began again in the late 1940's.

TABLE 1. Summary of *Mirounga angustirostris* Censuses On San Nicolas Island, 1949 to 1981.

Date	Number of Pups	Source	Total population estimate based on pup count extrapolations
1949 May 11-12		Bartholomew 1951	159 ¹
1959 Jan 23	48 ²	Bartholomew and Boolootian 1960	160 ¹
1964 Feb 9	78	Odell 1972	312
1971 Feb 6-7	344 ³	Odell 1974	1376
1972 Feb 8	399	Antonelis <i>et al.</i> 1981	1596
1977	693	Le Boeuf and Bonnell 1980	2772 ⁴
1981 Mar 14	1523 ³	This study	6092

¹ Actual count of seals.

² First account of pupping.

³ Includes dead pups of the year.

⁴ Authors estimated 2960.

We surveyed the beaches of San Nicolas Island on 19-21 January, 16-17 February, and 14 March, 1981, counting all pups of the year and noting their locations on each survey. Adult elephant seals were not included in the counts. Additional incidental observations were made in February 1982. Our purpose was to estimate the size of the island population on the basis of pup production and to compare locations of pupping activity with those described in previous surveys. All counts were made by direct observation on foot at close range; hand counters and 9X binoculars were used when necessary.

Our highest pup count was 1,523 in March (Table 1). From this number we estimate the 1981 elephant seal population on San Nicolas to be 6,092 animals. The estimate is based on the assumption that the ratio of the total colony size to annual pup production is 4:1 (Peterson and Le Boeuf 1969, DeLong and Johnson 1976). Our estimate indicates that the island population has grown an average of 16% per year since 1971 and at about 22% per year since 1977. This is in general agreement with published growth rates of other growing elephant seal populations (Bonnell *et al.* 1981; Antonelis, Leatherwood and Odell 1981). Our estimated population growth rate represents the combined effects of pupping and recruitment within the San Nicolas Island breeding population, immigration from other breeding sites to San Nicolas Island, and emigration from San

Nicolas to other breeding sites. The relative contributions of immigration and emigration to the growth of the San Nicolas population are unknown, but we have evidence that both processes occur. During our February census eight tagged female seals with newborn pups were observed. Four had been tagged at San Miguel Island, California, three at San Nicolas Island, and one at Isla de Guadalupe, Mexico. All were located within the 1971 breeding area. Female elephant seals tagged as pups on San Nicolas have joined other breeding colonies, primarily to the north (Reiter, Paikén, and Le Boeuf 1981). A consistent trend of northerly movement of elephant seals involved in establishment of new colonies has been observed (Le Boeuf, Ainley, and Lewis 1974; Reiter *et al.* 1981).

The total linear distance of beach used for pupping increased from 5 km in 1971 (Odell 1974) to 11 km of shoreline in 1981 (Figure 1). The western limit of the pupping area changed little between 1971 and 1981, although the number of pups born near the west end was substantially higher in 1981 than in 1971 (Figure 1). Between 1971 and 1981 there was an increase in the utilization of beaches used for breeding of about 5 km to the east. In February 1982, two dependent pups were observed on the northwest side of the island (Figure 1), which extended the breeding range by another 5 km. Much of the northwest end of San Nicolas Island is characterized by rocky shoreline of a type seldom used by elephant seals for breeding. In 1982 the seals also extended their breeding area 1.2 km to the east. The total breeding range on the island is now about 17 km.

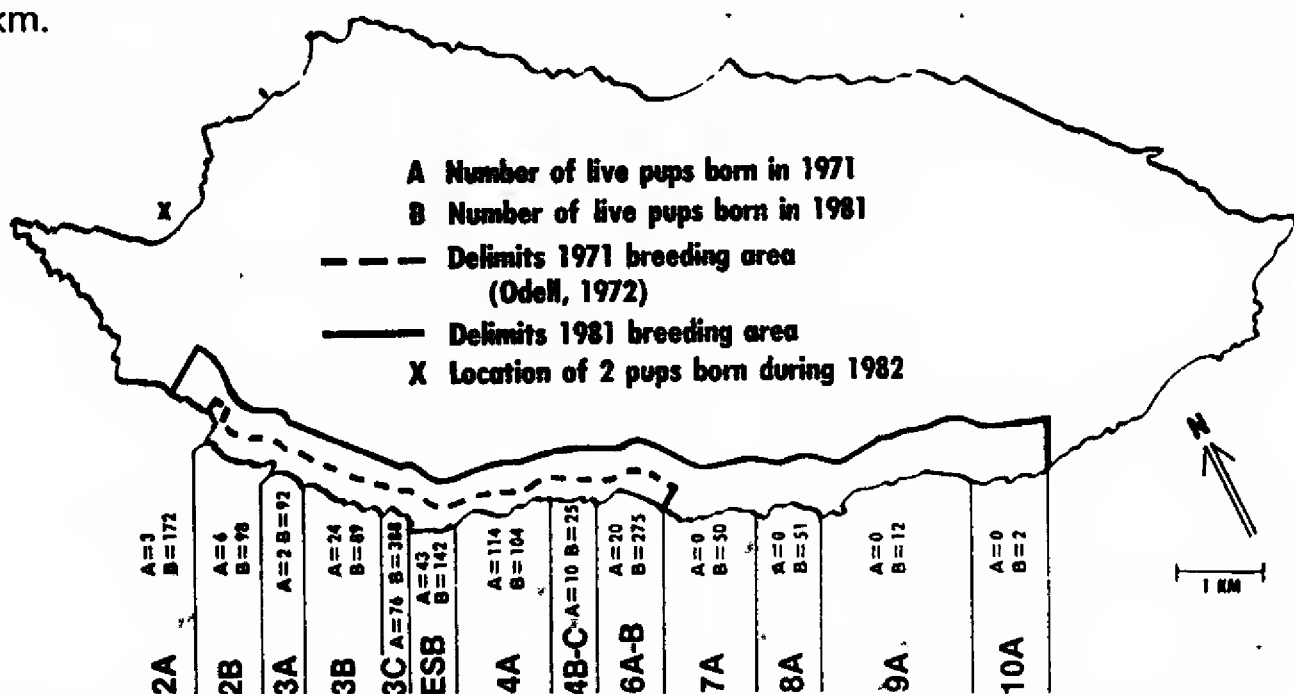


FIGURE 1. Distribution of elephant seal pups, March 1971 and 1981, San Nicholas Island. (area designations from Odell 1972)

Although expansion of the pupping area has been primarily eastward since 1971, only 115 pups in 1981 were produced beyond the eastern limits of the 1971 pupping area. While the number of pups born in the center of the breeding range has increased substantially over the past 10 years, those beaches lying in the periphery of the 1971 pupping range have experienced the largest increases in pup production (Figure 1). A number of sand and cobble beaches, apparently suitable for pupping but presently unused, occur on the northern, eastern, and southeastern shores of the island.

We counted 25 dead pups during our February census (1.7% of the February count). Heavy swells in January may have washed some dead pups out to sea

before our count. Odell (1974) estimated pup mortality to be 1.6 to 3.7% per year on San Nicolas Island during 1969–1971. Rates of pup mortality for Ano Nuevo Island, California, ranged from 13.0% to 40.0% per year from 1968 to 1980, (Le Boeuf and Briggs 1977, Reiter *et al.* 1981). On the Farallon Islands, one of the more recently reoccupied breeding areas, pup mortality has ranged from 7% to 71% during the period 1974–1976 (Ainley *et al.* 1977).

In summary, the colony of northern elephant seals on San Nicolas Island continues to grow exponentially. In recent years, pup production has increased most rapidly at the west end of the breeding area. Although the length of the breeding area has approximately tripled since 1971, many beaches which appear suitable for pupping remain unused. We feel that population growth should continue and that expansion of breeding areas will also continue as current breeding beaches become saturated.

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LITERATURE CITED

- Ainley, D. G., H. R. Huber, R. P. Henderson, T. J. Lewis, and S. Morrell. 1977. Studies of Marine Mammals at the Farallon Islands, California, 1975–76. Final report to U. S. Marine Mammal Commission, Washington, D. C. (Contract MM5AC020). Natl. Tech. Info. Serv., PB266–249. 32 p.
- Antonelis, G. A., S. Leatherwood, and D. K. Odell. 1981. Population growth and censuses of the northern elephant seal (*Mirounga angustirostris*) on the California Channel Islands, 1958–1978. Fishery Bull., 79(3): 562–567.
- Bartholomew, G. A. 1951. Spring, summer, and fall censuses of the pinnipeds on San Nicolas Island, California. J. Mamm., 32: 15–21.
- Bartholomew, G. A., and R. A. Boolootian. 1960. Numbers and population structure of the pinnipeds on the California Channel Islands. J. Mamm., 41: 366–375.
- Bonnell, M. L., B. J. Le Boeuf, M. O. Pierson, D. H. Dettman, G. D. Farrens, C. B. Heath, R. F. Gantt, and D. J. Larsen. 1981. Summary of marine mammal and sea bird surveys of the Southern California bight area 1975–1978. Vol. 3, 214 p. Investigator's reports, Part 1—Pinnipeds of the Southern California bight, Univ. Calif. Santa Cruz, Calif., Final Report to the Bureau of Land Management, Under Contract AA550–C17–36. Natl. Tech. Info. Serv., PB81–248171. 557 p.
- DeLong, R. L., and A. M. Johnson. 1976. Increase in the northern elephant seal population on San Miguel Island, California. Unpubl. Manuscr. Natl. Oceanic Atmos. Admin., Natl. Marine Fishery Serv., Northwest Fishery Center, Seattle, Washington. 10 p.
- Le Boeuf, B. J., D. G. Ainley, and T. J. Lewis. 1974. Elephant seals on the Farallons: Population structure of an incipient breeding colony. J. Mamm., 55: 370–385.
- Le Boeuf, B. J. and K. T. Briggs. 1977. The cost of living in a seal harem. Mammalia, 41: 167–195.
- Le Boeuf, B. J. and M. L. Bonnell. 1980. Pinnipeds of the California Islands: Abundance and distribution. p. 475–493. In D. M. Power (ed). The California Islands: Proceedings of a multidisciplinary symposium. Santa Barbara Museum of Natural History, Santa Barbara, California. 787 p.
- Odell, D. K. 1972. Studies on the biology of the California sea lion and the northern elephant seal on San Nicolas Island, California. Dissertation. Univ. Calif., Los Angeles, XV + 168 p.
- Odell, D. K. 1974. Seasonal occurrence of the northern elephant seal, (*Mirounga angustirostris*), on San Nicolas Island, California. J. Mamm., 55: 81–95.
- Peterson, R. S., and B. J. Le Boeuf. 1969. Population study of seals and sea lions. Trans. North Am. Wildl. Nat. Resour. Conf., 34: 74–79.
- Reiter, J., K. J. Panken, and B. J. Le Boeuf. 1981. Female competition and reproductive success in northern elephant seals. Animal Behaviour, 29: 670–687.
- James L. Bodkin, Ronald J. Jameson. U. S. Fish and Wildlife Service, Denver Wildlife Research Center, Piedras Blancas Field Station, P. O. Box 70, San Simeon, CA 93452, and Glenn R. Van Blaricom, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Center for Marine Studies, 273 Applied Sciences, University of California, Santa Cruz, CA 95064. Accepted for publication July 1983.

NORTHWARD OCCURRENCE OF THE OPALEYE *GIRELLA NIGRICANS*, AND THE SHARPNOSE SEAPERCH, *PHANERODON ATRIPES*

A specimen of the opaleye, *Girella nigricans*, (262 mm SL) was captured on hook and line at Otter Rock, Lincoln County, Oregon on 14 July 1982 by Herbert D. Linker of Oregon City, Oregon. Although the fish was caught on a nereid worm, its stomach contained only algae, according to Mr. Linker.

Otter Rock is at latitude 44° 45' N. Miller and Lea (1972) give the northern limit of *G. nigricans* as San Francisco, about lat 37° 45' N, so the new record is approximately 670 km north of the previously known distribution of the species. The Otter Rock specimen is deposited in the fish collection of the Department of Fisheries and Wildlife, Oregon State University, catalog number OS 9112.

Although the following account of the sharpnose seaperch, *Phanerodon atripes*, might not strictly establish a northern range extension because voucher specimens are not in the Oregon State University collection, we believe it to be of interest because it represents a situation in which a species entered an area that apparently was suitable for growth but not for reproduction.

Lea (1972) discusses the range and abundance of the sharpnose seaperch, noting the northern limit as Bodega Bay and reporting a resurgence of the population in Monterey Bay during the 1960's. He noted that a survey of sport fisheries, including spearfishing, from 1958 through 1960, from Point Arguello, to the Oregon border, disclosed only four sharpnose seaperch. In 1961, this species began to appear in spearfishermen's catches in Yaquina Bay, Oregon. The fish were recognized as different from the similar white seaperch, *P. furcatus*, and some were brought to the senior author for identification. Later the species appeared in trawl catches. In 1961 and 1962, several specimens, including five males (91–110 mm SL) and three females (82–106 mm SL) were brought to the Oregon State University campus but were not catalogued into the fish collection; they were taken to a laboratory detached from the campus for study and apparently inadvertently discarded. Charles Gnose, who conducted a systematic sampling program in Yaquina Bay in 1963, recorded a trawl-caught specimen of *P. atripes* on 12 June 1963; that specimen also cannot be found.

Beardsley (1969) carried out extensive trawl sampling in Yaquina Bay in the mid-1960's but did not report the capture of *P. atripes*. Both Beardsley and the senior author acted as judges at scuba diver's "species contests" during the same period but did not record additional *P. atripes*. The species has not been taken in Yaquina Bay since 1963 in spite of extensive collecting activity throughout the bay in many different years.

Although immigrants of *P. atripes* could survive for a time in Yaquina Bay, conditions suitable for reproduction apparently were not present there in the 1960's and the immigrants (possibly offspring of a few venturesome gravid females) died without issue.

LITERATURE CITED

- Beardsley, A.J. 1969. Movement and angler use of four food fishes in Yaquina Bay, Oregon. Dissertation. Oregon State University. 173 p.

Lea, R.N. 1972. Southern geographical records for four surfperches, Family Embiotocidae, with notes on a population resurgence of the sharpnose seaperch. Calif. Fish Game, 58(1): 27-31.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish and Game, Fish Bull., (157) 235 p.

—Carl E. Bond, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331 and Robert E. Olson, Department of Fisheries and Wildlife, OSU Marine Science Center, Newport, OR 97365. Accepted for publication September 1983.

THE OXEYE OREO, *ALLOCYTTUS FOLLETTI* MYERS, FROM THE BERING SEA

On 8 August 1979 an oxeye oreo, *Allocyttus folletti*, 302 mm SL was collected in the Bering Sea at lat 59°48'N, long 178°44'W while the senior author was monitoring ground fishing for the National Marine Fisheries Service aboard the Japanese stern trawler, RYUHO MARU #37. Fishing gear was a standard otter trawl with a mouth width of 30 m and a vertical opening of 6 m. The net was towed at a depth of 500 m over relatively flat, clay mud bottom. The specimen is deposited in the collection of fishes, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, OS 7895; it was identified as *A. folletti* by William N. Eschmeyer, California Academy of Sciences.

The morphometric and meristic data from the Bering Sea specimen agree with those reported by Myers (1960), Abe and Hotta (1962), and Anderson, Caillet and Antrim (1979).

Other Bering Sea specimens of *Allocyttus* have been reported from an unidentified area of the Bering Slope (Federov 1973). Two oxeye oreos were collected by observers aboard foreign fishing vessels in the northwestern Bering Sea in the winter of 1981. The first (UW 20832, 242 mm SL) was taken on 24 February at lat 59°20'N, long 178°09'W, depth 600 m and the second (UW 20831, 185 mm SL) on 10 March at lat 58°33'N, long 176°17'W, depth 530 m (Kevin Howe, University of Washington, pers. commun.).

LITERATURE CITED

Abe, T. and H. Hotta. 1962. An addition to the Japanese piscifauna. Japanese J. Ichthyology, 8(3/4): 152-156.

Anderson, M.E., G.M. Caillet and B.S. Antrim. 1979. Notes on some uncommon deepsea fishes from the Monterey Bay area, California. Calif. Fish Game, 65(4): 256-264.

Federov, V.V. 1973. Ichthyofauna of the continental slope of the Bering Sea and some aspects of its origin and formation. Izv. Tikookean Nauchno Issled. Inst.

Rybn. Kos. Okeanogr., 87: 3-41. Transl. Dept. of the Environ., Fishr. and Mar. Serv. series 3345. Pacific Biological Station, Nanaimo, British Columbia.

Myers, G.S. 1960. A new zeomorph fish of the Family Oreosomatidae from the coast of California with notes on the family. Stanford Ichthyological Bull., 7(4): 80-98.

—Sid F. Cook, Argus Associates, P.O. Box 237, Corvallis, OR 97339 and James Long, Collection of Fishes, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331. Accepted for publication September 1983.

COLOR VARIATION IN THE SEVENGILL SHARK, *NOTORYNCHUS MACULATUS* AYRES, ALONG THE CALIFORNIA COAST

During the course of investigating various life history aspects of the sevengill shark, *Notorynchus maculatus*, along the California coast I noted distinct color variation in specimens from different geographic regions. Ayres (1855) described the color of the sevengill as, "Dark bluish gray above with numerous small irregular black blotches; lighter below." Daniel (1934) described coloration in the sevengill shark as being uniformly drab dorsally and lighter ventrally. Scattered over the drab background is an irregular pattern of spots. Hence, the specific name for the sevengill, *maculatus*, meaning spotted (Ayres 1855). The spotting extends over the dorsal surface of both the paired and unpaired fins. These spots vary in size from minute dots to blotches exceeding the diameter of the eye pupil (Daniel 1934). Hart (1973) listed sandy gray to reddish brown in his description of the sevengill. Jordan and Evermann (1896) described sevengill color as sandy gray to blackish.

I examined over 120 sevengill sharks from California during a 20 month period. The presence of irregular black spots dorsally, shading to a lighter coloration ventrally, was consistent in all specimens. However, a difference was found in the background coloration of the dorsum between sevengills collected in Humboldt Bay (lat 40° 52' N) and San Francisco Bay (lat 37° 47' N).

The dorsal background color of sevengills collected in Humboldt Bay typically ranged from a pale silvery gray to reddish brown. This background color was observed in both sexes. Although no observations were made on small specimens (< 2100 mm TL), coloration did not appear to be size related. This coloration was consistent for all sevengills observed in Humboldt Bay. Sevengills collected in San Francisco Bay had a dorsal background color ranging from olive-brown to muddy gray. These colors also did not appear to be related to size or sex. This was based on observation of 83 sevengills that ranged from 450 to 2680 mm TL. With one exception, these colors were consistent for all specimens examined from San Francisco Bay.

On 16 June 1983, off Hunter's Point, San Francisco Bay, a piebald sevengill, 1170 mm TL, was caught while pole fishing (Figure 1). The shark was caught at a depth of fifty feet, using Pacific mackerel, *Trachurus symmetricus*, as bait. This sevengill had a white background dorsally with exceptionally large dark spots. The spots ranged in size from 3 to 18 mm in diameter. Spotting on the extreme dorsum was clumped, while spotting on the sides was irregular; spots extended onto both the paired and unpaired fins. Laterally, this specimen had the same olive-brown coloration as that of a normal sevengill. The snout, and dorsal edge of both paired and unpaired fins were olive-brown. Color faded ventrally. The eye color was black, consistent with normal eye coloration.

Internal examination of this sevengill revealed no apparent differences from other sevengills of a comparable size. Examination of the stomach revealed a partially digested bat ray, *Myliobatis californica*. Examination of the reproductive tract indicated this specimen, a male, was immature as expected at this size.

Retention of normal coloring along the lateral surface of the body and fins suggests that this sevengill represents an example of piebald coloration. Whether

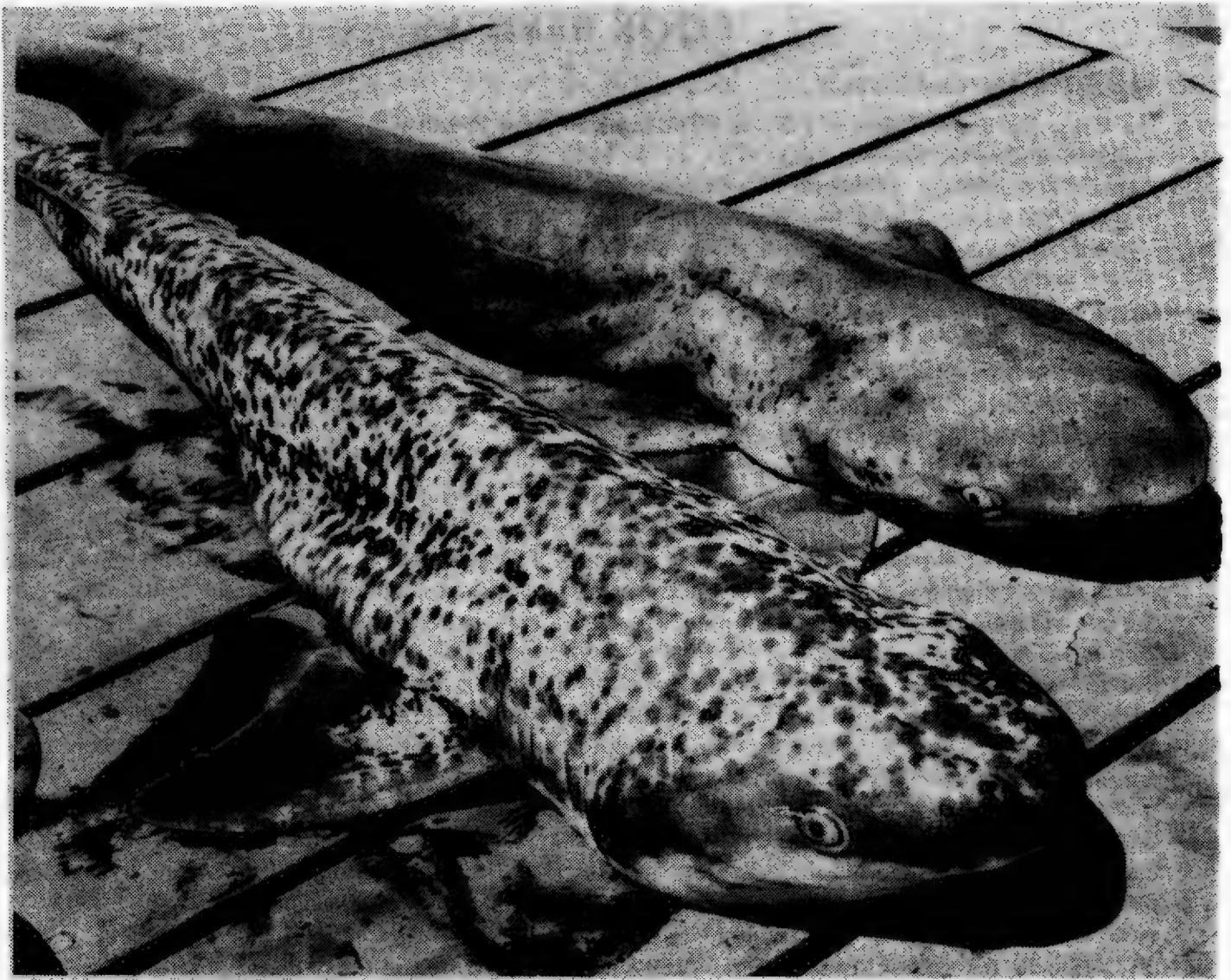


FIGURE 1. Piebald sevengill (foreground) alongside a sevengill (rear) with normal coloration. Photograph by author.

the piebald condition observed in this specimen was induced from a hormonal or dietary deficiency is unknown. The piebald coloration exhibited in this specimen is believed to be the first of its kind described for an elasmobranch.

ACKNOWLEDGMENTS

I would like to thank the following people for their time and consideration. K. Bates and D. Kittredge for their efforts in providing the numerous sevengill sharks I examined. G. Cailliet and E. Ebert for reviewing the manuscript. L. Compagno for suggesting the term piebald as an appropriate description. T. Ebert for his help in the collection of data for this study. Appreciation is also extended to R. N. Lea who reviewed this manuscript and provided many helpful suggestions.

LITERATURE CITED

- Ayres, W.O. 1855. [Description of *Notorynchus maculatus*.] Proc. Calif. Acad. Sc., 1 (Pt. 1): 72-73.
Daniel, J.F. 1934. The elasmobranch fishes. Univ. of Calif. Press, Berkeley, California. 332 p.
Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Can., Bull., 180, 740 p.
Jordan, D.S. and B.W. Evermann. 1896. The fishes of north and middle America. Bull. U.S. Nat. Mus., no. 47, Pt 1, 1240 p.
—David A. Ebert. Moss Landing Marine Laboratories, P.O. Box 223, Moss Landing, Ca. 95039. Accepted for publication October 1983.

BOOK REVIEWS

AQUATIC ENTOMOLOGY

The Fisherman's and Ecologist's Guide to Insects and Their Relatives by W. Patrick McCafferty. Science Books International, Boston, Mass. 1981. xv + 1448 pp. \$50.00.

Aquatic Entomology, as the subtitle suggests is a guide for fishermen and ecologists. It is, however, much more widely useful and anyone interested in the aquatic insect fauna of North America will find this volume a welcome addition to his library.

The text is profusely illustrated with black and white drawings and includes 124 color plates of larvae, pupae and adults of selected species. Quotations from poetry, prose and other non-technical literature illustrate the long-standing human fascination with aquatic insects and their habitats. The wide text margins provide more than adequate space for notations if one is so inclined. References which are particularly useful to anyone wishing to pursue his interest beyond the limits of this book are included at the end of each chapter.

The "serious angler" will be interested in the frequent mini-discussions of those species which are used as patterns for artificial flies. These discussions and any others of particular interest to fishermen are preceded in the text by an illustration of a stylized tied fly.

The book is conveniently divided into three parts. Part I includes a history of aquatic entomology, correlations between aquatic insect biology and fly fishing, applications of aquatic entomology, and the use of common and scientific names. In general, this section is most useful to those readers with little or no previous knowledge of entomology or aquatic biology. Also in Part I is a simple introduction to insect anatomy, life history, habitat, biology and taxonomy which assists the novice in locating and identifying aquatic insects. The techniques and equipment used in collecting aquatic insects are also discussed. There is also a very brief chapter on non-insect aquatic invertebrates likely to be encountered by the fisherman or anyone spending time in or near aquatic habitats.

Part II is divided into chapters on the aquatic orders of insects. For each order there is a general description of the larvae, pupae and adult stages, life history, habitats, behavior and classification. Each chapter also includes a discussion and keys to the families within the order. The keys are particularly useful in that each couplet is accompanied by line drawings illustrating the character(s) of concern. This pictorial key greatly facilitates the identification process. Other insects which might be confused with those in the order under discussion are mentioned in each chapter.

Part III includes chapters on terrestrial insects associated with aquatic habitats, common freshwater crustaceans, and common freshwater arachnids. Although the discussion of the crustaceans and arachnids is shorter than I would like (they are obviously outside the focus of this book), the inclusion of these common aquatic invertebrates is very useful. Their treatment, although brief, will enable anyone to recognize the major groups.

A special appendix which identifies mayfly species by both their "fishermen's name" and their scientific name is included as is a glossary to technical terms used in the book.

This book is a readable and informative introduction to the world of aquatic insects. The common names of insects are emphasized and scientific jargon is minimized. The picture keys are especially useful for the non-specialist. This will be a valuable book for anyone whose interest or occupation brings him or her into frequent contact with aquatic insects.—LARRY L. ENG

WATERFOWL ECOLOGY AND MANAGEMENT: SELECTED READINGS

Compiled by: John T. Ratti, Lester D. Flake, and W. Alan Wentz; The Wildlife Society, Bethesda, Maryland; 1982; 1328 pp; \$20.00.

For those people working with waterfowl in both management and research, this is one of the most important books published in recent years. It is a compilation of 134 articles selected from numerous journals on various aspects of waterfowl ecology and management.

The objective of the compilers in publishing this book was to put together a comprehensive group of readings suitable as an academic textbook and as a professional reference book. I feel that they have accomplished this within the limitation of 1328 pages.

The book contains many of the more significant articles on waterfowl ecology and management published in the past 20 years yet goes back to the 1940's for articles of historical significance. It is divided into eight sections: Historical I, Reproductive Ecology II, Population Influences and Characteristics III, Food Habits and Feeding Ecology IV, Management Economics V, Movement and Migration VI, Wintering Waterfowl VII, and Evolutions, Hybridization and Speciation VIII.

The three larger sections (II, III, V) are further divided into subsections. Each section and subsection contains a selected bibliography that is intended to direct the reader to additional papers on specific subjects. WARREN C. RIENECKER

LAKE MANAGEMENT

By S. E. Jorgensen. Pergamon Press Inc. Elmsford, New York; 1980. xii + 167 pp; \$45.00.

The author states in the introduction, "The scope of this book is to introduce its readers to the up-to-date management tools which enable us to meet lake management problems.", and "It is my hope that in this book biologists will find examples of how models can be built on a sound ecological basis." That was also my hope in reading this book, but unfortunately that was not the case. I found the book more of a review and synopsis of various accepted models than an introduction on the use of models, and it was directed more towards engineers, chemists and those already familiar with these models than to biologists desiring to learn more about them. He explains all biological terms and processes completely, for example, "Plants have photosynthetic pigments, one of which, chlorophyll is present in almost all photosynthetic organisms.", yet he uses chemistry terms such as Avogadro's number, without explanation and casually refers to various models, "... the well-known Monod model for nutrient limitation. . .", "Microbial biodegradation . . . expressed by means of a Michaelis Menten expression. . .", and "Available data might fit either the Langmuir or Freundlich adsorption isotherms.", without any elucidation.

He begins Chapter 1, titled Lake Management Problems, with a paragraph describing the water supply problems of Los Angeles. A very timely topic. However, his last statement on Los Angeles, "Drinking water is supplied in bottles—no longer from taps." is blatantly wrong, very misleading to those unfamiliar with the water situation in California, and it damages the credibility of his other examples.

The chapter "Modelling Fish Production in Lakes" is only eight pages long, so the information given is but a brief overview. He cites the original author(s) of the models presented, but, two citations that I looked up were incomplete. Jones and Hall (1973 and 1974) are given in the reference section only as "In: Bartlett and Hiorns (1973), pp. 35–62" and "In: Blaxter (ed.) (1974): 87–102." respectively; and neither Bartlett and Hiorns (1973) nor Blaxter (1974) are listed.

On the positive side I found the section on "Modelling the eutrophication in a data-poor situation" useful. It showed how to make a simple model using published data on 1) natural P and N loads from land; 2) natural P and N loads from precipitation; and 3) artificial P and N loads, and then predict the nutrient concentration and eutrophication in a lake. The author states, "It is possible in this way to test different wastewater treatment programmes and answer such questions as: should N or P be removed? With what approximate efficiency, if the transparency has to be improved twice or more?"

The chapter on "Restoration Methods" was also valuable. It presented "... a survey of the existing methods". It divides restoration into two classes: 1) reduction of external loading and 2) intervention in the lake ecosystem. The author states that these must often work hand in hand, that intervention in the lake ecosystem is useless without reduction of external loading. He gives eight methods of intervention in the lake ecosystem; most, unfortunately, they are described in half a page or less.

The author is a chemist and an engineer by training and profession. He is the General Secretary of the International Society for Ecological Modelling (ISEM), and Editor-in-Chief of *Ecological Modelling* and the *ISEM Journal*. He is undoubtedly well qualified to write a book on modelling the various processes in lakes but he has missed his targeted goal of introducing biologists to modelling. And the considerable number of typographical errors, and incomplete references is disappointing in an author who is Editor-in-Chief of two prestigious journals.—DARLENE McGRUFF

DISTRIBUTION AND ECOLOGY OF STREAM FISHES OF THE SACRAMENTO-SAN JOAQUIN DRAINAGE SYSTEM, CAL. (U.C. Publications in Zoology, Vol. 115)

By Peter B. Moyle, Jerry J. Smith, Robert A. Daniels, Thomas L. Taylor, Donald G. Price, and Donald M. Baltz, 256 pages, softback, \$14.25.

In 1966 the Department of Fish and Game published its generally excellent "Inland Fisheries Management," which since that time has served as a "technician's bible" for thousands of fishery workers throughout North America. Then, in 1982, Peter Moyle and several of his graduate students at U.C. Davis published the document currently under discussion. I was intrigued, upon reviewing both works, at the evolution of thought during the intervening 16 years which spanned the environmental awakening of the 1970s.

Following an extensive treatment of gamefishes, "Inland Fisheries Management" devotes chapters to "Rough Fish Management" and "Chemical Control of Undesirable Fishes," then follows with descriptions of eight species (six of them native to California) which are implicitly listed as targets for the wrath of the insensitive fishery manager.

Moyle and his co-authors, as might be expected, correctly view the native fishes within their area of study as integral components of a once magnificent ecosystem which we will probably never fully understand. All that may be said with certainty is that the insensitive progress of civilization has done little for California's native fish fauna.

One must consider this work, which addresses the biology and interactions of the fishes within a major area of California, as perhaps the most significant contribution yet to our understanding of California's native fish fauna. And, as our knowledge of this fauna increases, so does the likelihood of our ability to conserve it.

Aldo Leopold observed that "Our ability to perceive quality in nature begins, as in art, with the pretty. It expands through successive stages of the beautiful to values as yet uncaptured by language." For the subject at hand, we might paraphrase Leopold as follows: "Our ability to perceive quality in fishes and fish communities begins with the materialistic. It expands through successive stages of appreciation to values as yet uncaptured by language."

"Distribution and Ecology of Stream Fishes" provides a wealth of information on relative abundance, distribution, and life history of great interest and value to the general ecologist, while providing sufficient detail on habitat preference and species interaction to be plugged readily into an IFG computer program. It should be required reading for all students of aquatic biology and should be referred to frequently by anyone who makes his living by managing California's inland fish populations.

It is my hope that this superb volume might motivate agency fishery biologists to conduct similar inventories and studies within their own areas of responsibility. Such an endeavor, while providing a wealth of management information, could do much to bring about the inevitable realization that our greater obligation lies not in striving to achieve an "acceptable" catch rate per angler hour, but in leaving for posterity a species diversity and abundance equal to or greater than the one we inherited. It just might be that *Gila crassicauda* did not die entirely in vain.—PHIL PISTER

PLANNING OF AQUACULTURE DEVELOPMENT

An Introductory Guide Prepared by T.V.R. Pillay; published by arrangement with the Food and Agriculture Organization of the United Nations by Fishing News Books Ltd., 1 Long Garden Walk, Farnham, Surrey, England; printed in Great Britain by The Press at Coombelands Ltd., Addlestone Surrey; 1977; 71 pp. This "guide" is the outcome of a Round Table Discussion on the "Strategy for Development of Aquaculture as an Industry", that was organized by the Food and Agriculture Organization of the United Nations in cooperation with the Svany Foundation of Norway. Thirteen participants from seven nations, including two from the United States, were in attendance for the Round Table Discussion that was convened at Svany, Norway, July 1-10, 1974.

The "guide" is arranged into 10 sections, plus a single page of references; and at first glance one immediately recognizes the ease at which the various sections, and subsections can be located. Subject areas include: (i) basic data required for aquaculture planning, (ii) levels and patterns of aquaculture industry, (iii) auxiliary industries, (iv) manpower requirements and training of personnel, (v) research support and extension services, (vi) investment decisions and financing, (vii) legal aspects, and (viii) environmental effects of aquaculture development. These topics are not covered in-depth; but this is not the purpose of the guide. Rather, points are raised that should be considered by both administrators and investors to assist in the decision-making process. For example the question is raised as to whether aquaculture should aim at the production of cheap food for the common man or high-priced food for the luxury market or export. Rationale for this decision is largely a function of socio-economic policies of the particular country, and development objectives.

Overall the "guide" serves to stimulate thinking in areas that may otherwise be overlooked in the aquaculture planning process. I recommend it to administrators and investors. It could serve the latter group particularly well, and result in fewer venture failures.—EARL E. EBERT

FARMING THE EDGE OF THE SEA (SECOND EDITION)

By E. S. Iversen; Fishing News Books Ltd., 1 Long Garden Walk, Farnham, Surrey, England; Whitefriars Press Ltd., London and Tonbridge; 1976; 436pp.

The surge of interest in marine aquaculture (sea farming) that marked the mid-1960's to early 1970's, also, and understandingly, produced a spate of publications. Among these was "Farming the Edge of the Sea". This text was well-received, and most everyone having an interest in marine aquaculture has some familiarity with this text, and most have "gained" from its contents. Continued interest in marine aquaculture, particularly in developing countries, accompanied by new technologies and findings; and in spite of the failures of many ventures, has prompted this second edition.

The second edition of "Farming the Edge of the Sea", represents a well-balanced approach to an

understanding of marine aquaculture principles and practices. The format is similar to the first edition in being organized into six major sections: (i) general, (ii) procedures, (iii) presently farmed species, (iv) potential species, (v) problems, and (vi) evaluation. Inclusive are 17 chapters that present information that ranges from the use of artificial reefs for fishery enhancement, to economic aspects of sea farming. This latter chapter is a welcome addition, although by the author's account it is of necessity a general treatment. Nevertheless, it is quite useful in that it presents a number of examples of varied aquaculture operations, considerations, and potential pitfalls.

The section on presently farmed species provides "just-enough" coverage to gain a general understanding of the various cultivation methods, and future perspectives. Accounts of species are arranged in the standard format, beginning with the cultivation of seaweeds, proceeding through representative invertebrates, and terminating with fin fish. Inclusive, and illustrated, are methods employed for cultivation of red seaweeds, oysters, clams, mussels, scallops, abalones, shrimps, milkfish, yellowtail and mullet.

The text includes a glossary; selected references by chapter, including references since the first edition that are set-off; and a general index.

Containing over 200 illustrations, "Farming the Edge of the Sea", represents a valuable reference for all those having an interest in marine aquaculture.—EARL E. EBERT

ANIMALS OF THE TIDAL MARSH

By Franklin C. Daiber; Van Nostrand Reinhold Co. Inc., New York, 1982; 422p., \$19.95

Animals of the Tidal Marsh is not a field guide to the birds and bees of coastal wetlands, but rather a highly comprehensive collection and careful synthesis of technical literature pertaining to the biology and natural history of animals characteristic of an ignored habitat, that of the marsh lands inundated by tidal exchanges. Despite its technical nature it is written in a light style which is easily followed. The chapters divide this topic into five major disciplines—zonation and distribution, interaction with vegetation, food and feeding, reproduction, and community structure. These chapters are further sub-divided by taxonomic groupings. The taxonomic coverage is superb covering Protozoa and Meiofauna through fish, birds and mammals. Second only to the wide taxonomic coverage is that of regional coverage. The author gives equal time to east, west and gulf coasts, a challenge in itself.

As explained in the preface, the text is primarily a review of existing literature with an occasional personal observation by Dr. Daiber included. Seven hundred and four publications are cited. The older literature is brought up to date with citations as recent as 1980. So exhaustive are the literature citations that Dr. Daiber has included an authors index in addition to the subject and scientific names indices.

The last chapter—Opportunities for the Future—suggests dozens of research topics for future investigation. This chapter is an obvious outgrowth of any review of a topic as broad as this one. The suggestions presented, which are categorized by discipline, are borne from gaps in the voluminous although limited literature.

Equally as enjoyable as the authors reader-friendly style is his use of illustrative materials. Eighty-three tables and 98 figures supplement the text to aid the reader in understanding the subject matter. The only feature I find disturbing in the slightest, is the monotone established by the regrettably unavoidable repetitive referral to previous studies and reports.

Should your needs concern any aspect of the tidal marsh, whether preparing an EIR and seeking information on the ability of small mammals to utilize seawater, or in need of reproductive information on a tidal marsh amphipod for your laboratory toxicity studies, I feel you will find this book to be an invaluable reference and usable atlas to the complex avenues of this subject.—D. W. BEHRENS

LABORATORY ANIMAL MANAGEMENT—MARINE INVERTEBRATES

By Committee on Marine Invertebrates: Institute of Laboratory Animal Resources, the Assembly of Life Sciences, and the National Research Council; National Academy Press, Washington, D.C., 1981; 382 p., \$19.75

Laboratory Animal Management—Marine Invertebrates is not only the product of unique authorship, but follows a quite different format than that of its sister textbooks on this subject. The text is the combined effort of a committee of seven prominent marine animal researchers and curators, chaired by Dr. Ralph T. Hinegardner of the University of California at Santa Cruz, and the contributors of thirteen other investigators.

The use of marine invertebrate species as laboratory test animals is rapidly increasing, particularly in the fields of toxicity bioassay testing, physiological, behavioral and biomedical research and in

natural products resources investigations. With this increase in use comes a concomitant need for up-to-date information on live animal curation. This book is written with expeditious solutions in mind, and is not burdened with the technical explanations so prevalent in previous texts. The first part of the book is a general review of the mechanics of live marine animals curation, covering such generic topics as collection and transportation of animals and aquarium equipment, to more specialized subject such as plant growth; mono- and tissue cultures; diseases, symptoms and treatments; and anesthetics. Chapter 10 is particularly useful as it reviews, by phylum, those species commonly used a laboratory animals. This chapter includes a list, by species names, of literature citations for marine invertebrates that have been cultured in the laboratory, each of which contains information specifically directed towards maintenance and culture.

The second part of the book consists of chapters giving detailed directions on the care, handling, food requirements and problems associated with the curation of specific species or groups of marine invertebrates. These include sea anemones, polychaetes, two gastropods, bivalves, crabs and a sea urchin.

Three extremely resourceful appendices include: 1) the addresses of Fish and Game agencies for acquiring permits and licenses required to collect and hold marine invertebrates; 2) an annotated list of aquarium equipment and supplies sources; and 3) a list of suppliers of marine organisms and marine unicellular algae cultures. The book also contains an exhaustive bibliography listing some 1,200 references, with citations as recent as 1980.

Despite the technical nature of this topic, it is written in a reader-friendly style. The real benefit of this publication is the attention given to all the little problems that arise in the course of any live animal study. The committee and the contributing authors most certainly kept Murphy's law in mind during the production of this book due to the detail given to alerting the reader to the difficulties, problems and shortcomings of using various procedures, equipment, and species when working with marine aquaria. I recommend this text to the naive beginner as well as the experienced curator. To the former, it will provide a healthy respect for the situation he is about to tackle; for the latter, it provides a fresh review of the state-of-the-art.—D. W. BEHRENS